CHAPTER 12

The blue, green and grey water footprint of rice from both a production and consumption perspective

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ABSTRACT: The aim of this chapter is to make a global assessment of the green, blue and grey water footprint of rice, using a higher spatial resolution than earlier studies and using local data on actual irrigation. Evapotranspiration from rice fields is calculated with the CROPWAT model; the distinction between green and blue water evapotranspiration is based on data on precipitation and irrigation. Water pollution from N-fertilizers is estimated based on application rates. The calculated green, blue and grey water footprints of paddy rice are converted into estimations of the green, blue and grey water footprints of derived rice products on the basis of product and value fractions. International virtual water flows related to trade in rice products are estimated by multiplying export volumes by their respective water footprints in the exporting countries. Per nation, the water footprint of rice production is estimated by aggregating the water footprints per production region. The water footprint of rice consumption is estimated for each nation by aggregating the water footprints in the regions where the rice consumed in a nation is grown. For rice importing countries, the water footprint related to rice consumption is thus partly (or fully) outside the country itself.

In the period 2000–04, the global average water footprint of paddy rice is 1,325 m^3/t (48% green, 44% blue, and 8% grey), which is much lower than previous estimates. There is about 1,025 m^3/t of percolation in rice production. The global water footprint of rice production is 784,000 Mm^3/yr. The ratio of green to blue water varies greatly, both over time and space. In countries like India, Indonesia, Vietnam and Thailand, Myanmar and the Philippines, the green water fraction is substantially larger than the blue water fraction. In the USA, however, the blue water fraction is 3.7 times the green water fraction and in Pakistan it is 5.6 times.

During the period 2000–04, the global virtual water flows related to international rice trade was 31,000 Mm^3/yr (45% green, 47% blue, and 8% grey). The share of blue water component in the average rice export is a bit higher than in the average rice production.

The consumption of rice products in the EU27 alone is responsible for the annual evaporation of 2,279 Mm^3 of water and polluted return flows of 178 Mm^3 around the globe, mainly in India, Thailand, the USA and Pakistan. The water footprint of global rice consumption creates relatively low stress on the water resources in India compared to that in the USA and Pakistan, as in the latter cases rice is extensively irrigated with scarce blue water resources.

Keywords: rice, trade, water footprint, green water, blue water, fertilizer, pollution

1 INTRODUCTION

Rice is one of the major crops feeding the world population and is most important in South Asia and Africa. Large irrigation projects are often constructed to meet the water demand in rice production. As a result, rice is one of the largest water consumers in the world. This chapter quantifies how much fresh water is being used to produce rice globally, distinguishing between two different sources: irrigation water withdrawn from gound- or surface water (blue water) and rainwater (green water). It also quantifies the volume of polluted water related to the use of nitrogen fertilizers in rice production (grey water).

Rainwater and irrigation water are necessary for rice growth in two ways: to maintain soil moisture and –in wet irrigation– to maintain the standing layer of water over the paddy field. In the major rice producing regions of the world, the crop is grown during the wet (monsoon) season, which reduces the irrigation demand by effectively using rainwater.

As much of the standing water in paddy fields percolates and recharges groundwater and surface water, there is a substantial contribution to the local blue water availability. Percolation can be seen as a loss to the paddy field, but for the catchment area it is not considered as a loss, because the water can be captured and reused downstream (Bouman *et al*., 2007b). In some irrigation systems in flood plains with impeded drainage or systems in low lying deltas a continuous percolation can even create shallow groundwater tables closer to the surface (Belder *et al*., 2004). Although the document focuses on the estimation of evapotranspiration from rice fields, it also estimates percolation flows, because evapotranspiration and percolation are both part of the soil water balance.

2 METHOD AND DATA

There are mainly two systems of rice production: wetland systems and upland systems. About 85% of the rice harvest area in the world is derived from wetland systems. About 75% of rice production is obtained from irrigated wetland rice (Bouman *et al*., 2007b). In Asia, rice fields are prepared by tillage followed by puddling. The soil layer is saturated and there is standing water during the entire growth period of the crop. In the USA, Australia, parts of Europe and some Asian countries, rice land is prepared dry and flooded later.

In the production database of the FAOSTAT data (2009), 115 countries are reported as rice producers. During the period of 2000–04, the average annual global production of rice was 592 million tonnes (Mt) [1 t = 1,000 kg] with an average yield of 4.49 t/ha. The yield ranges from nearly 1 t/ha (Jamaica, Micronesia, Congo, Brunei Darussalam, Comoros, Chad, Liberia, Mozambique, Congo D.R., Sierra Leone, etc.) to 8.7 t/ha (Australia). In India, the rainfed yield ranges between 0.5–1.6 t/ha, whereas that of irrigated rice is 2.3–3.5 t/ha (Gujja *et al*., 2007).

Table 1 presents production data for the thirteen countries with the largest average annual production during the period 2000–04. These countries account for more than 90% of the global production during this period. These thirteen countries together account for more than 82% of the total export of rice-equivalent globally. About 6–7% of the world rice production is traded internationally. A complete list of rice producing countries with production statistics is presented in Appendix B.

The average fertilizer application rates for the top-13 rice producing countries have been taken from IFA *et al*. (2002) and are presented in Table 1. The use of animal manure reduces the need for chemical fertilizer use in crop fields. This is reflected in lower fertilization application rates in the database, mainly in developing countries. There is no readily available global dataset on use of animal manure in rice fields. Moreover, the spatial distribution of the fertilizer within a country is also not well known, therefore results on water pollution should be treated cautiously.

The reference crop evapotranspiration (ETo) and monthly average rainfall data for the concerned climate stations are taken from the CLIMWAT database (FAO, 1993) for all countries, but from FAOCLIM (FAO, 2001) for the USA. The ETo data in these databases are derived using the Penman-Monteith equation as described in Allen *et al*. (1998). Using the CROPWAT model (FAO, 1992), the crop evapotranspiration (ETc) and the available effective rainfall are calculated for the given set of data on ETo, monthly rainfall, Kc and the crop calendar. Rice crop coefficients are taken from Allen *et al*. (1998). Monthly data on rainfall and ETo are distributed within the month to obtain data per five days. As CROPWAT 4 (FAO, 1992) is not suitable to calculate the crop water requirement for rice (Clarke *et al*., 1998), we have used it only to get the values of ETc and the available effective rainfall for a time step of 5 days. For each of the thirteen countries, the crop

Table 1. Statistics for the thirteen largest rice producing countries during the period 2000–04.

Countries	Average production (Mt/yr)[1]	Global share (%)[1]	Average area harvested (Mha/yr)[1]	Average yield (t/ha)[1]	N (kg/ha)[2]	P_2O_5 (kg/ha)[2]	K_2O (kg/ha)[2]
China	177.66	30.0	28.67	6.19	145	60	40
India	126.50	21.4	43.06	2.93	67.7	24.2	9.4
Indonesia	52.01	8.8	11.64	4.47	105	22	14
Bangladesh	37.22	6.3	10.64	3.50	72	15	10
Vietnam	33.96	5.7	7.51	4.52	115	45	42
Thailand	26.80	4.5	10.04	2.67	62	33	17
Myanmar	22.58	3.8	6.43	3.51	35	12	4
Philippines	13.32	2.3	4.06	3.28	51	15	11
Brazil	11.07	1.9	3.37	3.28	40	50	30
Japan	10.99	1.9	1.71	6.44	78	92	72
USA	9.52	1.6	1.29	7.40	150	60	60
Pakistan	6.91	1.2	2.34	2.95	52.2	6.9	0.2
Korea, Rep.	6.81	1.2	1.05	6.51	110	70	80
Sub total	535.35	90.5	131.80	–	–	–	–
Global total	591.75	100.0	150.67	4.49	–	–	–

[1]*Source*: FAOSTAT data (2009). [Mt = 10^6 t]; [1 t = 1,000 kg]; [Mha = 10^6 ha]
[2]Average fertilizer use in rice cultivation. *Source*: IFA *et al*. (2002).

evaporative demand (ETc) is calculated for each season of rice production in all the regions using the climate data (FAO, 1993; 2001) for the concerned regions (Appendix A).

The CROPWAT model suggests a number of methods to estimate the effective rainfall, and the method of the USDA SCS (United States Department of Agriculture, Soil Conservation Service) is one of them. As this method does not take into account the soil type and the net depth of irrigation, it gives a lower estimation of effective rainfall compared to the water balance approach (Mohan *et al*., 1996) and is not very accurate. However, as the water balance approach is highly data demanding, the USDA SCS method is widely used in estimating the effective rainfall in agriculture water management (Cuenca, 1989; Jensen *et al*., 1990). We have also chosen the USDA SCS method for the present study. The USDA SCS equations to estimate effective rainfall are:

$$P_{eff} = \frac{P_{total}}{125} \times (125 - 0.2 \times P_{total}) \text{ for } P_{total} \leq 250\,\text{mm}$$
$$P_{eff} = (125 + 0.1 \times P_{total}) \text{ for } P_{total} \geq 250\,\text{mm}$$

where *Peff* is the effective rainfall and *Ptotal* is the total rainfall in the concerned period.

For rice cultivation in wetland systems, paddy fields are prepared and the soil is kept saturated. The common practice is to first prepare land by puddling. This is done by saturating the soil layer for one month prior to sowing. The volume of water (SAT) necessary for this stage is assumed to be 200 mm as suggested by Brouwer & Heibloem (1986). As lowland rice is grown in a standing layer of water, there is a constant percolation and seepage loss during this period. Percolation loss (PERC) is primarily a function of soil texture. It varies from 2 mm/day (heavy clay) to 6 mm/day for sandy soil. As rice is mostly grown in soil with more clayey texture, for the present study we have taken 2.5 mm/day as an average (Brouwer & Heibloem, 1986) for the entire period of rice cultivation except for the last 15 days when the field is left to dry out for easy harvesting. A water layer is established during transplanting or sowing and maintained throughout the growing season. Although the volume of water needed for maintaining the water layer (WL) is available for percolation losses and to meet the evaporative demand of the crop during the last phase of paddy growth, it is necessary to get this volume of water at the beginning of the crop period (Figure 1).

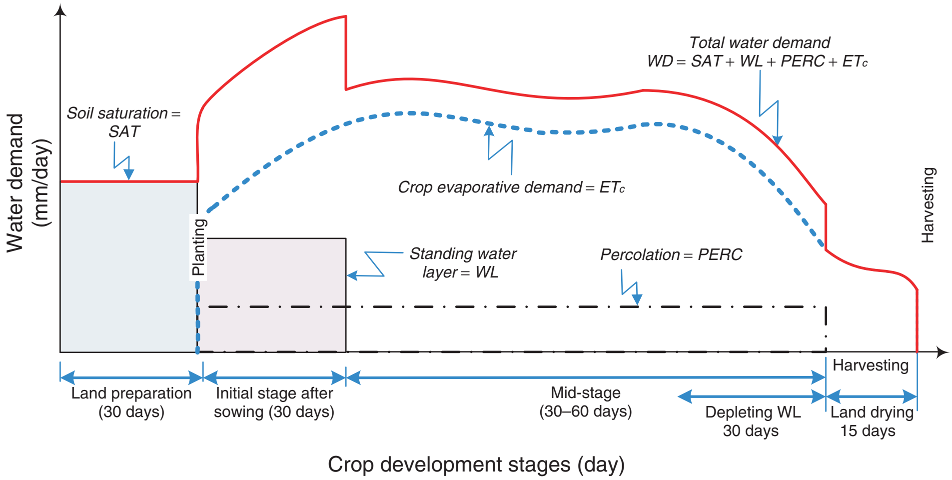

Figure 1. The schema used to estimate the water demand at different stages of crop growth.

In this study, it is assumed that a water layer of 100 mm is established in the month of sowing. A time step of five days is chosen for the calculation. The total water demand (WD) is calculated by adding ETc, WL, SAT and PERC for each time step.

For the last 15 days prior to the harvesting when the land is left to dry out, the volume of water required for evaporation is supplied by the effective rainfall in the period and any residual soil moisture maintained from the previous stages. Approximately 30 days before the land is left to dry out, the standing layer of water is slowly left to deplete without any augmenting water supply to maintain the water layer. This practice makes the best use of water supplied to maintain the WL in the previous stages. The method, thus, accounts the storage of water in time either as soil moisture or as water layer over the rice field.

Any residual soil moisture after the harvest is not included in the water footprint estimation. It is assumed that the initial soil moisture before the land preparation is negligible. It is also assumed that the contribution of capillary rise from the shallow groundwater table in the rice fields is negligible. The net inflow and outflow of the overland runoff from the bunded rice fields are assumed to be zero as well. The schema to measure the depth of water available (WA) for use in different stages of crop development is presented in Figure 2.

The water use in the rice fields is calculated for each 5-day cumulative period using the schema as presented in Figure 3. If the total water demand (WD) is less than total water available (WA), green water use is equal to the demand WD. In cases where the WD outstrips WA, the deficit is met by irrigation water supply. This deficit is called irrigation water demand. If a paddy field is 100% irrigated, it is assumed that the *blue water* use in crop production is equal to the deficit. For areas equipped with partial irrigation coverage, the blue water use is estimated on a pro-rata basis.

In order to show the sort of detail we have applied, we give an example here for India. There are two major rice production seasons in India, known as *Kharif* (monsoon season) and *Rabi* (dry season). For the period of 2000–04, the share of *Kharif* production to the gross national production (GNP) is 86% and the remaining 14% is from *Rabi*. The data for harvested area, crop period, irrigated share, crop yield and total production are taken from the Directorate of Rice Development (2001). Crop water use depends on the crop calendar adopted and it is difficult to analyse multiple crop calendars that possibly exist in a region. The study assumes a single representative calendar is valid per region in India. The planting and harvesting time for the crop are assumed to be at the average of these dates gathered from various sources such as the Directorate of Rice Development (2001), IRRI (2006), and Maclean *et al.* (2002). The major *Kharif* rice producing regions in India

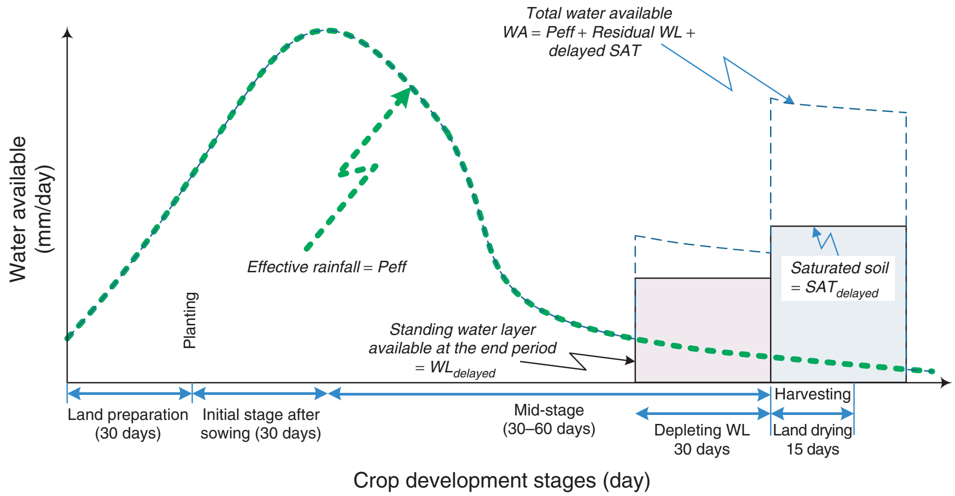

Figure 2. The schema used to estimate the total water available at different stages of crop growth.

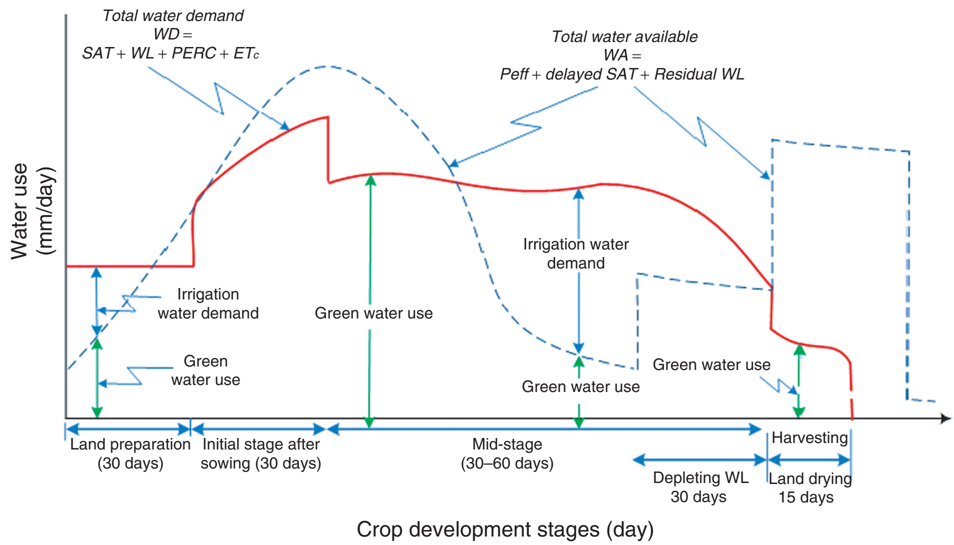

Figure 3. Distinguishing the green water use and irrigation water demand.

are Uttar Pradesh, West Bengal, Punjab, Bihar, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Orissa and Assam, producing 85% of the national *Kharif* rice production (Appendix A). The major *Rabi* rice producing regions are Andhra Pradesh, West Bengal, Tamil Nadu, Karnataka and Orissa, producing 92% of the national *Rabi* rice production. The state-wise data for irrigated area are taken from the Directorate of Rice Development (2001). The rice production in *Rabi* is assumed to be fully irrigated and the remainder of the total irrigated area is attributed to the *Kharif* rice. The irrigation water requirement (m^3/ha) and the green water use (m^3/ha) are calculated per state for the major rice producing regions. For the remaining regions, the average irrigation water requirement and green water use are calculated based on the data for the major regions. Blue water use is calculated by multiplying the irrigation requirement with the irrigated area in each season per state. The green water use in irrigated areas is calculated by multiplying the green water use (m^3/ha) by the total area in each season.

The example of India is followed for each of the other twelve countries. The planting and harvesting dates for all of the crop producing regions in these countries are chosen based on the major crop season in these regions (USDA, 1994; Directorate of Rice Development, 2001). The climate stations representing the production regions, regional share of production (%) to the total national production and irrigation coverage per region are presented for all countries in Appendix A. For each production region, we have estimated the green water use, irrigation demand and blue water use based on whether it is a *wetland system* or an *upland system*. The national averages of green and blue water use are calculated based on the data per region and the share of production of each region to the total national production.

2.1 *The water footprint of paddy rice*

The water footprint is the volume of water used to produce a particular good, measured at the point of production. A number of studies have been conducted to quantify the water footprint of a large variety of different crop products (Chapagain & Hoekstra, 2003; Chapagain & Hoekstra, 2004; Oki & Kanae, 2004 ; Hoekstra & Hung, 2005; Chapagain, 2006; Chapagain & Hoekstra, 2007; Hoekstra & Chapagain, 2008). These studies provided a broad-brush to the global picture since the primary focus of these studies was to establish a first estimate of global virtual water flows and/or national water footprints. More detailed crop-specific studies have been produced for cotton (Chapagain *et al*., 2006), tea and coffee (Chapagain & Hoekstra, 2007), tomato (Chapagain & Orr, 2009) and sugar beet, sugar cane and maize (Gerbens-Leenes & Hoekstra, 2009). This is the first detailed global assessment of rice.

The calculation framework to quantify the water footprint of rice is based on Hoekstra & Chapagain (2008), Chapagain (2006), and Hoekstra *et al*. (2009). The water footprint of a product (m^3/unit) is calculated as the ratio of the total volume of water used (m^3/yr) to the quantity of the production (t/yr). The water footprint has three components: the green water footprint (evaporation of water supplied from the rain in crop production), blue water footprint (evaporation of the irrigation water supplied from surface and renewable groundwater sources) and the grey water footprint (volume of fresh water polluted in the production process). Most studies on the calculation of water footprints of products have taken the two evaporative components only (i.e. green and blue water footprint), excluding the grey water footprint. In an earlier study, Chapagain & Hoekstra (2004) have assumed a constant percolation loss of 300 mm of water per year from the rice field and added that to the total water footprint of rice. This is inconsistent, however, with the approach taken for other products in the same study. In the present study, a clear distinction between the evaporation and percolation is made. The percolation flow is not included in the water footprint.

The volume of polluted water depends both on the pollutant load and the adopted concentration standard for surface and ground water bodies for individual categories of pollutants. To avoid double counting, the grey water use in crop production should take the maximum of any of these requirements for individual pollutant categories. Due to data limitations, this study looks at nitrogen (N) as a representative element for estimations of the grey water footprint.

Nitrogen recovery rarely exceeds 30–40% in wet-land rice production systems (De Datta, 1995). In these systems, rice is primarily grown in clay soils thus restricting the nitrogen loss by leaching. Loss of nitrogen by runoff is also controlled in most rice fields. Ammonia (NH_3) volatisation and denitrification are recognized as major nitrogen loss mechanisms that affect the efficiency of urea and other N fertilizers in irrigated wetland rice (De Datta, 1995). In general, irrigated systems have higher fertilizer application rates than rainfed systems. For example, in India during the period of 2003–04, the fertilizer application in irrigated crop land amounted to 22% of the total national fertilizer application, whereas for rainfed crops was only 9.6% (Table 2). In Indonesia 52% of the fertilizers used are applied to rice (FAO, 2005b).

In wetland rice cultivation, the global NH_3 loss to the atmosphere from the annual use of 12 Mt of mineral fertilizer (N) amounts to 2.3 Mt N/yr, or 20% of the N application, and 97% of this occurs in developing countries (FAO & IFA, 2001). For a continuous flooding rice system, the denitrification is never more than 10%, where for an intermittent fallow system it is up to 40%

Table 2. Fertilizer used for rice production in India during 2003–04.

	Gross harvested area (10^6 ha)	Share in national fertilizer consumption (%)	Fertilizer consumption (kg/ha)			
			N	P_2O5	K_2O	Total
Irrigated	24.0	22.2	103.4	32.8	18.8	155.0
Rainfed	20.7	9.6	56.6	14.5	6.5	77.6
National	44.7	31.8	81.7	24.3	13.1	119.1

Source: FAO 2005a.

(Fillery & Vlek, 1982). As reported in Xing & Zhu (2000), there is about 0–5% of leached nitrogen from upland rice fields, though this varies from 10 to 30% if the surface runoff is taken into account. Zhu *et al*. (2000) have suggested the leaching losses to be 2% of the application rate. The magnitude of nitrogen leaching depends on soil conditions (irrigation frequencies, rainfall pattern, soil texture, percolation rate, etc.) and methods of fertilization application (application rate, time, agronomical practices, etc.). However, as the focus of this chapter is global in nature, a first-order estimation of the volume of water polluted is made following the method presented in Chapagain *et al*. (2006). In this document, we have taken a flat rate of nitrogen leaching equal to 5% of the nitrogen application rate.

Since 1991, the European Union (EU) member states have had to comply with the Nitrates Directive which aims to protect ground and surface waters from pollution by nitrogen (nitrates) originating from agriculture. The permissible limit of nitrates in surface and ground water bodies as set by the EU is 50 mg/L nitrate-NO_3. The standards recommendation by the EPA (2005) is 10 mg/L (measured as nitrogen). We have taken the number from the EU Nitrates Directive to estimate the volume of water necessary to dilute leached nitrogen to the permissible limit.

2.2 *The water footprint of processed rice*

Paddy is the most primary form of rice. The actual rice kernels are encased in an inedible and protective hull. Brown rice or husked rice has the outer hull removed, but still retains the bran layers that give it a characteristic tan color and nut-like flavor. Brown rice is edible but has a chewier texture than white rice. Milled rice is also called white rice. Milled rice is the product after milling which includes removing all or part of the bran and germ from the paddy.

On average, rice varieties are composed of roughly 20% rice hull, 11% bran, and 69% starchy endosperm. The endosperm is also known as the total milled rice which contains whole grains or head rice, and broken grains. Rice milling can be a one step, two steps or multi-step process. In a one step milling process, husk and bran removal are done in one pass and milled or white rice is produced directly out of paddy. In a two-step process, husk and bran are removed separately, and brown rice is produced as an intermediate product. In multi-stage milling, rice goes through a complex set of different processing steps. The maximum milling recovery (total milled rice obtained out of paddy, expressed as a weight percentage) is 69–70% depending on the rice variety. The global average of milling recovery is only 67%.

The water footprint of the primary rice crop is attributed to the processed products on the basis of so-called product fractions and value fractions (Chapagain & Hoekstra, 2004; Hoekstra *et al*., 2009). The product fraction is defined as the weight of a derived product obtained per tonne of root product. For example, if one tonne of paddy rice (the root product) produces 0.95 t of husked rice (the derived product), the product fraction of husked rice is 0.95. If there are more than two products obtained while processing a root product, we need to distribute the water footprint of the root product over its derived products based on value fractions and product fractions. The value fraction of a derived product is the ratio of the market value of the derived product to the aggregated market value of all the derived products obtained from the root product. To estimate

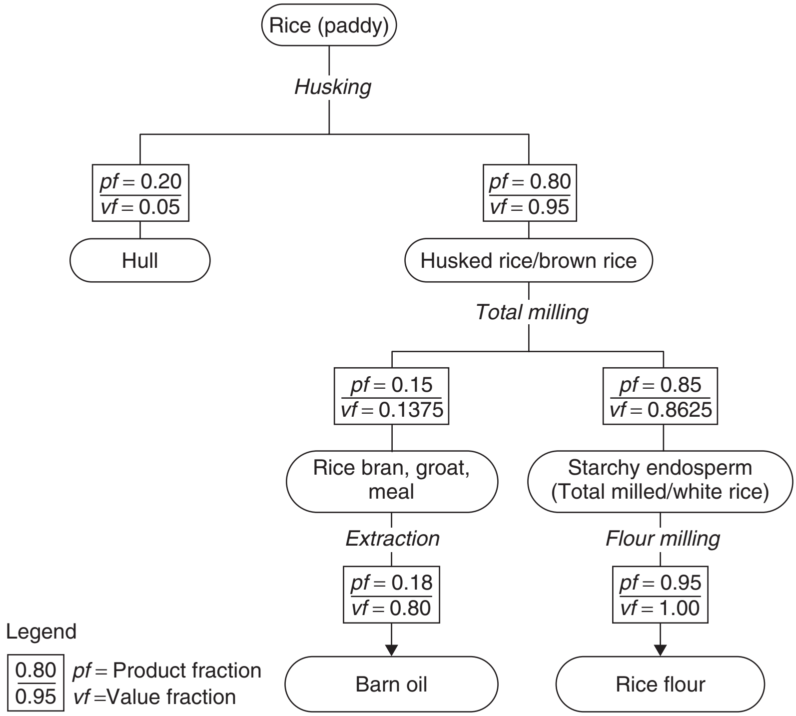

Figure 4. Product tree of rice showing value fraction and product fraction per rice processing stage.

the water footprint of various rice products originating from paddy, a product tree (Figure 4) is constructed showing the various products at various levels (primary, secondary and tertiary) along with their product fraction and value fraction. Based on these, the water footprints of the various derived rice products are calculated.

2.3 *Calculation of international virtual water flows*

The virtual water flow between two nations is the volume of water that is being transferred in virtual form from one place to another as a result of product trade. The virtual water flows between nations related to trade in rice products have been calculated by multiplying commodity trade flows (t/yr) by their associated water footprint (m^3/t) in the exporting country (Chapagain & Hoekstra, 2008). The virtual water export of a country is the volume of water used to make export goods or services. Similarly, the virtual water import of a country is the volume of virtual water imported through goods or services. Data on international trade of rice products are taken from PC–TAS (Personal Computer – Trade Analysis System) (ITC, 2006) for the period 2000-04[1].

2.4 *Calculation of the water footprint related to rice consumption in a country*

The water footprint of the consumption of rice in a nation can be divided into two parts, an internal and an external component. The internal water footprint of rice consumption refers to the consumption and pollution of national water resources for the part of rice produced and consumed

[1] The trade data on rice imports by Papua N. Guinea is erroneous in PC–TAS and thus discarded in estimating the international virtual water flows with all of its trading partner countries.

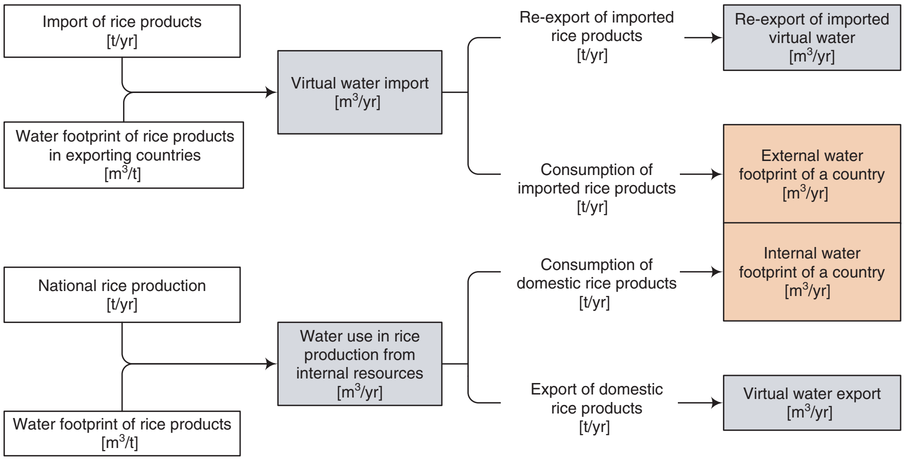

Figure 5. The calculation scheme for assessing the water footprint of national consumption of rice products.

Table 3. Depth of water used in rice production (mm/yr) for the thirteen major rice-producing countries. Period 2000–04.

	Evaporation		Pollution	Percolation	
	Green	Blue	Grey	Rain water	Irrigation water
China	228	302	73	209	277
India	314	241	34	231	178
Indonesia	260	217	53	226	188
Bangladesh	192	202	36	192	202
Vietnam	139	92	58	190	125
Thailand	252	149	31	210	125
Myanmar	297	133	18	268	120
Japan	219	258	39	224	264
Philippines	277	139	26	254	127
Brazil	260	220	20	227	192
USA	168	618	75	104	383
Korea, Rep.	232	253	55	198	216
Pakistan	124	699	26	73	412

internally. Any consumption of the part of imported rice would create equivalent size of the external water footprint of the country in locations where the rice is imported from. The internal and external water footprints are assessed following the scheme shown in Figure 5.

3 WATER FOOTPRINT OF RICE PRODUCTION

The calculated average water depth used in rice production in each of the thirteen major rice producing countries is presented in Table 3. In the USA, the evaporation is relatively high, at the same time the effective rainfall is much lower, making the irrigation volume one of the highest. Rice fields in both the USA and Pakistan are 100% irrigated, making the blue water footprint high in these countries.

Table 4. Total national water footprint of rice production and percolation of water in the thirteen major rice-producing countries (10^3 Mm^3/yr). Period 2000–04.

	National water footprint of rice production (evaporation + pollution)				Percolation and residual soil moisture			Total water use (WF + percolation)
	Green	Blue	Grey	Total	Green	Blue	Total	
China	65.2	86.5	20.8	172.5	60.0	79.5	139.5	312.0
India	136.3	104.5	14.7	255.5	100.4	77.0	177.4	432.9
Indonesia	30.3	25.3	6.1	61.7	26.3	21.9	48.2	110.0
Bangladesh	20.4	21.5	3.8	45.7	20.5	21.5	42.0	87.7
Vietnam	10.5	6.9	4.3	21.7	14.3	9.4	23.7	45.3
Thailand	25.2	15.0	3.1	43.3	21.1	12.5	33.6	76.9
Myanmar	19.1	8.5	1.1	28.8	17.2	7.7	24.9	53.7
Japan	3.7	4.4	0.7	8.8	3.8	4.5	8.3	17.1
Philippines	11.2	5.6	1.0	17.9	10.3	5.2	15.5	33.4
Brazil	8.8	7.4	0.7	16.8	7.6	6.5	14.1	31.0
USA	2.2	8.0	1.0	11.1	1.3	4.9	6.3	17.3
Korea, Rep.	2.4	2.6	0.6	5.6	2.1	2.3	4.3	10.0
Pakistan	2.9	16.3	0.6	19.9	1.7	9.6	11.3	31.2

The total water use (m^3/yr) for rice production in each country is calculated by multiplying the national harvested area of rice crops (ha/yr) with the corresponding depth of water (mm/yr) used in paddy fields. The water footprint of rice production is the sum of water evaporated from the rice fields and the volume of water polluted in the process. The results are presented in Table 4. It also presents the volume of water percolated or left over as residual soil moisture after the crop harvest in the fields. Total water use is the sum of the water footprint and percolation. The water footprint refers to a real loss to the catchment, while the percolation is actually not a loss to the catchment.

Table 5 shows the water footprint and percolation per unit of paddy rice produced (m^3/t). The figures follow from dividing total national water footprint and percolation related to rice production (m^3/yr) by the gross national paddy production per year (t/yr). The volume of water evaporated per tonne of rice is quite similar to the evaporation per tonne of wheat, as also noted in Bouman & Tuong (2001). The higher evaporation rates per hectare as a result of the standing water layer in rice fields are apparently compensated by the relatively higher yields of rice (Bouman *et al.*, 2007b).

Table 5 also shows the global average water footprint of rice, calculated based on the share of national production of the top-13 rice producing countries to the total global production. Since the export share of these 13 countries to the total export volume during the period 2000–04 differs widely, the global average water footprint of rice paddy is also calculated weighing the export share of these countries. As the top-13 largest rice producing countries contribute 82% to the global share of rice export, the difference between these two averages is not big. Global average results presented in the following sections are based on the global average water footprint based on production. Table 6 shows the global average water footprints of rice products.

Using the global average water footprint of paddy calculated and the production data for the rest of the countries, the global water footprint of rice production is estimated to be 784,000 Mm^3/yr (48% green, 44% blue and 8% grey) (Figure 6). The volume of water percolated in the rice fields plus any residual soil moisture left in the field after rice harvest is equal to 607,000 Mm^3/yr, about half of which (52%) is sustained by rainfall in the rice field. Including percolation, the total blue water use in the rice field becomes 636,000 Mm^3/yr, which is the number often quoted in the literature while referring to the total water used in rice production. If we add the total water footprint

Table 5. Water footprint and percolation per unit of paddy rice produced (m^3/t) in the thirteen major rice-producing countries. Period 2000–04.

	Water footprint				Percolation		
	Green	Blue	Grey	Total	Rain water	Irrigation water	Total
China	367	487	117	971	338	448	785
India	1,077	826	116	2,020	794	609	1,403
Indonesia	583	487	118	1,187	505	422	927
Bangladesh	549	577	103	1,228	550	578	1,128
Vietnam	308	203	127	638	420	277	697
Thailand	942	559	116	1,617	787	467	1,253
Myanmar	846	378	50	1,274	763	341	1,103
Japan	341	401	61	802	348	409	757
Philippines	844	423	78	1,345	775	388	1,163
Brazil	791	670	61	1,521	691	585	1,276
USA	227	835	101	1,163	141	517	658
Korea, Rep.	356	388	84	829	303	331	634
Pakistan	421	2,364	88	2,874	248	1,394	1,642
Average based on weighted production data	632	584	109	1,325	535	490	1,025
Average based on weighted export data	618	720	112	1,450	522	538	1,060

Table 6. The global average water footprint of rice products (m^3/t). Period 2000–04.

PC–TAS code	Product description	Green	Blue	Grey
100610	Rice in the husk (paddy or rough)	632	584	109
100620	Rice, husked (brown)	750	693	130
110314	Rice groats and meal	688	636	119
100630	Rice, semi-milled, milled, whether or not polished or glazed	761	704	132
100640	Rice, broken	761	704	132
110230	Rice flour	801	741	139

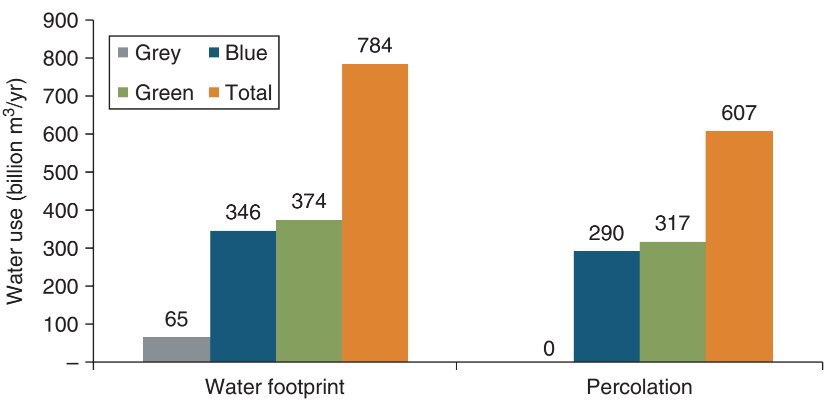

Figure 6. The global water footprint of rice production and the total volume of water percolated in rice fields (km^3/yr). Period 2000–04.

Table 7. Largest net-exporters and net-importers of virtual water related to the international trade of rice products.

Largest net exporters (Mm^3/yr)					Largest net importers (Mm^3/yr)				
	Green	Blue	Grey	Total		Green	Blue	Grey	Total
Thailand	5,607	3,327	691	9,625	Nigeria	1,528	1,204	211	2,943
India	2,764	2,119	298	5,181	Indonesia	788	682	149	1,620
Pakistan	428	2,405	90	2,923	Iran	670	721	97	1,489
USA	237	2,172	245	2,654	Saudi Arabia	650	694	82	1,426
Vietnam	595	392	246	1,233	Senegal	756	482	107	1,344
Uruguay	428	395	74	897	South Africa	701	509	88	1,298
Italy	417	370	74	861	Philippines	490	386	103	979
Egypt	307	284	53	644	Brazil	433	459	83	974
China	87	410	106	602	Japan	340	514	83	937
Australia	215	196	40	451	Malaysia	399	349	66	814

and the percolation water volume, it is equal to 1,391,000 Mm^3/yr, which is nearly the same as the global water use in rice fields (1,359,000 Mm^3/yr) as reported in Chapagain & Hoekstra (2004). Water footprints of rice production for all countries are presented in Appendix B.

4 INTERNATIONAL VIRTUAL WATER FLOWS

International trade in rice during the period 2000–04 resulted in a total international virtual water transfer of 31,100 Mm^3/yr (45% green water, 47% blue water, 8% grey water). This means that international rice trade is linked to the evaporation of 28,700 Mm^3/yr of water with an additional 2,400 Mm^3 of fresh water being polluted each year in the exporting countries.

The top ten largest gross virtual water exporters are Thailand (9,627 Mm^3/yr), India (5,185 Mm^3/yr), USA (3,474 Mm^3/yr), Pakistan (2,923 Mm^3/yr), China (1,296 Mm^3/yr), Vietnam (1,233 Mm^3/yr), Italy (1,048 Mm^3/yr), Uruguay (899 Mm^3/yr), Egypt (644 Mm^3/yr) and Australia (599 Mm^3/yr) covering nearly 87% of the total virtual water export international trade in rice products globally. The largest gross importers are Nigeria (2,944 Mm^3/yr), Indonesia (1,637 Mm^3/yr), Iran (1,506 Mm^3/yr), Saudi Arabia (1,429 Mm^3/yr), South Africa (1,348 Mm^3/yr), Senegal (1,346 Mm^3/yr), Brazil (1,010 Mm^3/yr), Japan (988 Mm^3/yr) and Philippines (979 Mm^3/yr) covering about 42% of the total import. Appendix D shows gross virtual water export and import for all countries.

Net imports of water are calculated by subtracting the gross export volume of water from the gross import volume of water, and vice versa for net exports. The largest net exporters and net importers are shown in Table 7.

The average annual blue virtual water import during the study period was 14,600 Mm^3/yr and the average green virtual water import was 14,100 Mm^3/yr. The total average annual virtual water flows including the pollution component was 31,100 Mm^3/yr. The share of green virtual water to the total global virtual water flows related to the international trade of rice products is 45%, and that of blue water is 47%.

The total virtual water flows related to international trade of rice according to Chapagain & Hoekstra (2004) was 64,000 Mm^3/yr for the period 1997–2001 (Table 8). This is quite comparable with the estimation in this document, which is 54,000 Mm^3/yr when percolation is also included. However, the calculation in Chapagain & Hoekstra (2004) does not separate the green and blue components, and is based on national average climate dataset. The earlier study does not separate percolation from the total virtual water flows. The former study gave an overestimation, as it was assumed that the total crop water requirements in the rice fields are always met either by rainfall or

Table 8. Global international virtual water flows by rice product (Mm^3/yr).

Product description	Current study *					Chapagain & Hoekstra **
	Green	Blue	Grey	Percolation	Total	Total virtual water flows
Rice flour	108	89	17	162	375	511
Rice groats and meal	6	5	1	9	21	24
Rice in the husk (paddy or rough)	662	1,392	192	1,430	3,675	2,776
Rice, broken	2,121	1,800	351	3,311	7,583	10,853
Rice, husked (brown)	1,417	1,715	258	2,423	5,813	5,302
Rice, semi-milled or wholly milled	9,768	9,591	1,561	15,447	36,367	44,741
Total	14,081	14,592	2,379	22,782	53,834	64,207

* Period 2000–2004. The assessment includes grey water.
** Period 1997–2001. The assessment does not separate different components of virtual water flows. It excludes grey water, but includes percolation in rice fields.

Table 9. Top-15 of countries with the largest water footprints related to rice consumption (Mm^3/yr). Period 2000–04.

Country	Water footprint (Mm^3/yr)				Per capita water footprint (m^3/yr)
	Green	Blue	Grey	Total	
India	133,494	102,425	14,385	250,305	239
China	65,154	86,050	20,680	171,884	134
Indonesia	31,097	26,005	6,262	63,364	299
Bangladesh	20,560	21,574	3,846	45,980	317
Thailand	19,640	11,654	2,421	33,714	547
Myanmar	18,989	8,483	1,118	28,591	612
Vietnam	9,860	6,496	4,074	20,430	256
Philippines	11,736	6,020	1,137	18,893	238
Brazil	9,186	7,869	757	17,812	99
Pakistan	2,480	13,935	521	16,936	117
Japan	4,084	4,923	748	9,755	77
USA	1,924	5,779	719	8,422	29
Egypt	3,467	3,203	599	7,269	105
Nigeria	3,478	3,005	548	7,031	54
Korea, Rep.	2,491	2,732	592	5,814	122

by irrigation water supply, which is not the case in general. On the other hand, the earlier estimate does not include the volume of water polluted in the process.

5 WATER FOOTPRINT OF RICE CONSUMPTION

The largest consumer of rice in terms of water is India, followed by China, Indonesia, Bangladesh, Thailand, Myanmar, Vietnam, the Philippines and Brazil. The composition of the water footprint related to rice consumption for the 15 largest countries is presented in Table 9. The per-capita water footprint of rice consumption is quite high in Thailand (547 m^3/yr) compared to India (239 m^3/yr), Indonesia (299 m^3/yr), China (134 m^3/yr) and the USA (29 m^3/yr). This variation is also because

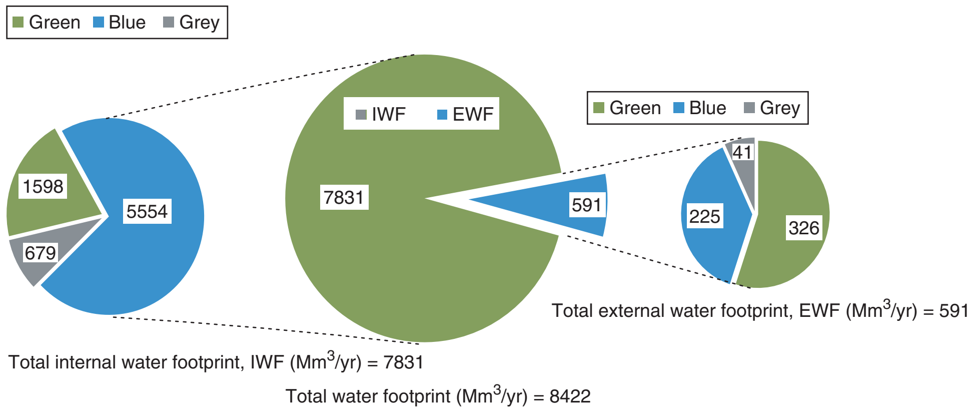

Figure 7. Water footprint of rice consumption in the USA (Mm^3/yr). Period 2000–04.

Table 10. External water footprint (EWF) of the USA by locations (Mm^3/yr). Period 2000–04.

	Green	Blue	Grey	Total	Share to the total EWF
Thailand	245	137	29	411	69.5%
India	47	34	5	86	14.5%
Pakistan	5	25	1	30	5%
China	9	12	3	24	4%
Australia	11	10	2	23	4%
Others	8	7	1	17	3%
Total	326	225	41	591	100%

the diet contains more rice in some countries compared to others. The complete list of countries with their water footprints related to rice consumption is presented in Appendix C.

From the perspective of food security as well as from the viewpoint of sustainable consumption it is interesting to know where water footprints related to national consumption actually *land*. We give here two examples, one for the USA and one for Europe. The total water footprint of the USA is 8,422 Mm^3/yr. The internal water footprint is relatively large (93% of the total water footprint) (Figure 7). The external water footprint of the USA is 591 Mm^3/yr and largely refers to water use in Thailand, India, Pakistan, China and Australia (Table 10).

In contrast to the USA, the sizes of the rice-consumption related internal and external water footprints of the EU27 are fairly comparable. Out of 5,335 Mm^3/yr, the internal component is 2,878 Mm^3/yr and the external one is 2,457 Mm^3/yr (Figure 8). More than 70% of the total external water footprint of the EU27 rests on eight countries, namely India, Thailand, USA, Pakistan, Egypt, Guyana, China and Vietnam. Figure 9 shows the external water footprint of the EU27 in each of these countries, distinguishing between the green, blue and grey water footprint. The largest share of the blue water footprint is for rice imported from the USA and Pakistan. Although the total footprint on India is the largest, a large fraction of it is made up of green water. Though the total footprint on Egypt, Guyana and Vietnam is much lower than in Pakistan, the grey component on these countries is relatively higher than in Pakistan.

6 DISCUSSION AND CONCLUSION

Rice is a staple food for 3,000 million people (Maclean *et al.*, 2002), especially in Southeast Asia, the Middle East, Latin America, and the West Indies. In terms of human nutrition and caloric

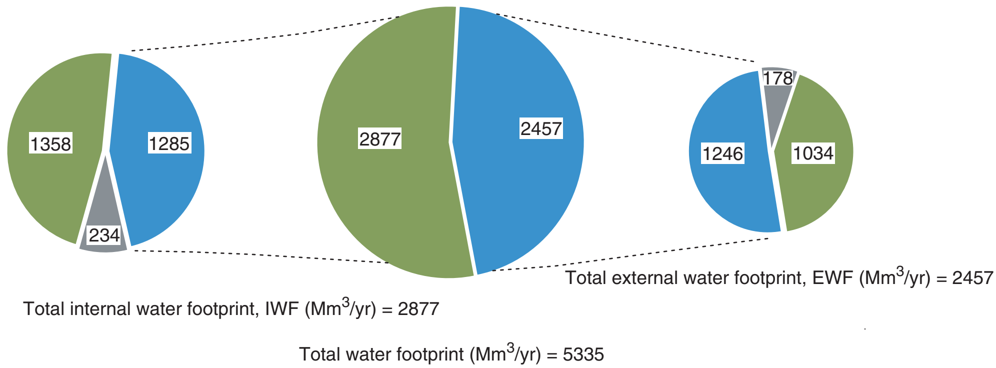

Figure 8. Water footprint of rice consumption in EU27 countries (Mm^3/yr). Period 2000–04.

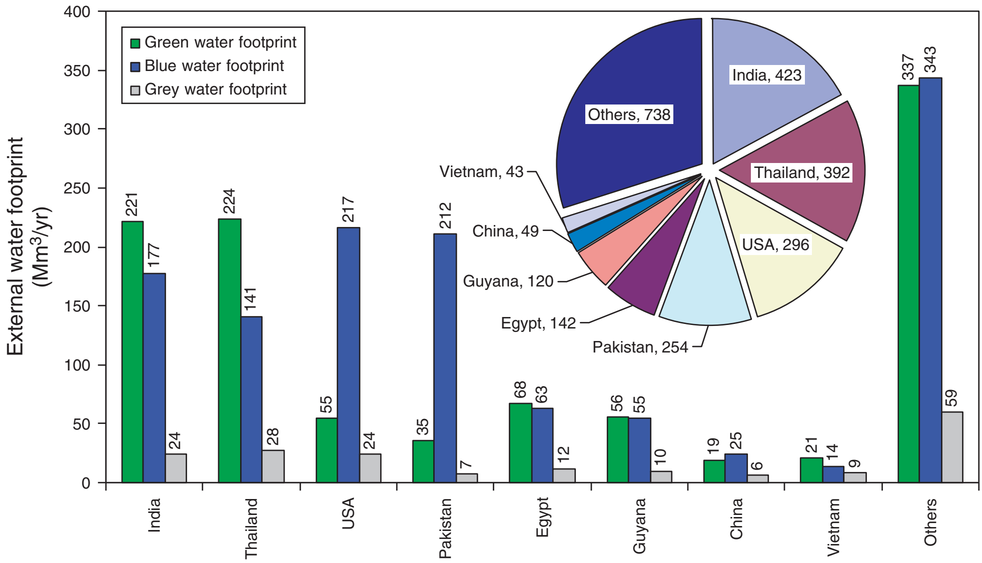

Figure 9. The external water footprint of rice consumption in the EU27. Period 2000–04.

intake, it provides nearly one fifth of the direct human calorie intake worldwide, making it the most important food crop (Smith, 1998; Zeigler & Barclay, 2008). Rice consumption exceeds 100 kg per capita annually in many Asian countries (compare for example with the USA average of 10 kg) and is the principal food for most of the world's poorest people, particularly in Asia, which is home to 70% of those who earn less than US$ 1 a day (Zeigler & Barclay, 2008). Rice production is deeply rooted in the socio-political culture in Asia which nearly produces nearly 90% of the global rice (Bouman *et al.*, 2007a).

The water footprint of rice production and consumption is quite significant in South Asian countries. However, in these countries most of the water footprint is rooted in the wet season, so that the contribution to water scarcity is relatively low in contrast to our general perception. Globally, there is nearly an equal share of green and blue water use in the total water footprint of rice. The green water footprint (rain) has a relatively low opportunity cost compared to the blue water footprint (irrigation water evaporated from the field). The environmental impact of the blue water footprint in rice production depends on the timing and location of the water use. It would need a dedicated analysis to estimate where and when blue water footprints in rice production constitute significant environmental problems, but from our results it is obvious that rice from the USA and Pakistan, where rice production heavily depends on blue water, will generally cause larger impacts per unit of product than rice from Vietnam. From a sustainable-consumption perspective, for countries or regions that import a lot of rice for own consumption, it may be relevant to compare the local impacts of different rice sources. Besides, in international context one may address the question why rice consumers like in the EU do not cover the actual water cost (costs of water scarcity and water pollution) that occurs in the countries from where the rice is obtained. Since irrigation systems are generally heavily subsidized and water scarcity is never translated into a price, the economic or environmental costs of water are not contained in the price of rice. The water cost may actually largely vary from place to place, depending on whether the rice comes from e.g. India, Thailand, the USA, Pakistan or Egypt, and depending on whether the rice is produced in the dry or the wet period.

In probably a majority of cases, the green water footprint of rice production does not constitute significant negative environmental or economic impacts. Rainwater allocated for rice production generally has no opportunity cost, which means that alternative uses of the rain (natural vegetation, other crops) would not give higher benefits. Storing rainwater in the fields reduces or delays surface runoff and may thereby flatten peak flows in downstream rivers, which may be useful in the wet season during heavy rains. On the other hand, this mechanism may be absent or even reversed when rice fields are already full of water up to the point of overflow, in which case rain will become runoff very quickly. Although the green water footprint in rice production may not constitute significant environmental problems, reduction of the green water footprint at a global level is probably key in reducing the blue water footprint in rice production. Better use of rain wherever possible, that means increasing yields per drop of rainwater, will reduce the demand for rice from areas where blue water is a necessary input.

From an economic point of view, reducing percolation of blue water in the rice fields is relevant, because it will reduce costs of water supply by reducing the absolute volume of water needed in the field. However, the environmental benefit may not be quite big as percolated blue water will remain within the same catchment as from where it was abstracted. As a lot of water is percolating in the first phase of the land preparation, a number of water saving technologies have been suggested (Bouman *et al*., 2007a), which are effectively used in the Phillippines, India and China. The direct dry seeding method can increase the effective use of rainfall and reduce irrigation needs (Cabangon *et al*., 2002) in the phase of land preparation. Another way to reduce percolation from fields is to use System of Rice Intensification (SRI). SRI suggests ways to improve rice yields with less water, the main advance is that it uses water just enough to keep the roots moist all the time without any standing water at any time. The argument behind SRI is that the main benefit of flooding the rice plant is to check the proliferation of weeds, thereby saving labour (Gujja *et al*., 2007), which can be a favourable option where the supply is limited or scarce.

Rice production is a so-called diffuse source of pollution and hence difficult to mitigate. The option to have optimal application of fertilizer so that the application matches exactly the plant uptake, as in the case of dry crops, is not suitable in rice production. There is inevitably percolation leaching a part of the fertilizer. The grey component of the water footprint can only be reduced with a reduction in the leaching of fertilizers and pesticides from the field, e.g. by increasing water use efficiency, using slow-release fertilizers and nitrification inhibitors, puddling the rice fields, planting catch and cover crops and using crop residues in situ (Choudhury & Kennedy, 2005). The loss of nitrogen may cause environmental and health problems. Although these problems cannot be alleviated completely, there are enough research findings that indicate that these problems can be minimized through a number of management practices (Choudhury & Kennedy, 2005). The fate of nitrogen in soil is mainly governed by different processes: plant-uptake, ammonia volatilization, de-nitrification and losses to surface (runoff) or ground water bodies (leaching). All these three processes are intertwined and it is hard to study them in isolation. A systematic analysis of fate of nitrogen should be carried out at field level to reveal any specific impacts on the system.

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Appendix A. Data on main regions of rice production within major rice producing countries.

Country	Crop season, major rice harvesting regions, share to the national production, irrigated area in % or ha, crop planting date, crop length in days and relevant climate stations
Bangladesh	Aus (14%, 100%, 15-Apr, 130d, Guwahati), T.Aman (40%, 100%, 01-Aug, 130d, Guwahati), Aman broadcast (6%, 100%, 15-Apr, 115d, Guwahati), Boro (40%, 100%,01-Dec, 170d, Guwahati)
Brazil	Rio grande (50%, 100%, 15-Nov, 120d, Passo Fundo & Bage), Minas Geralas (8%, 40%, 15-Nov, 120d,Pocos de Caldas), Mato Grosso (8%, 40%, 15-Nov, 120d, Cuiaba), Santa Caatarina and Parana (9%, 100%,15-Nov, 120d, Londrina & Puerto Stroessner), Goias (5%, 40%,15-Nov, 120d, Goiania), Maranhao and others (10%, 40%, 01-Jan, 120d, Quixeramobim), Tocantins (3%, 40%, 01-Jan, 120d, Tocantin), Sao Paulo (3%, 40%,15-Nov, 120d,Pocos de Caldas), Mato Grosso do sul (2%, 40%, 15-Nov, 120d, Campo Grande), Para (2%, 40%, 01-Jan, 120d, Quixeramobim)
China	**Single crop:** Hunan (1.44%, 90%, 1-May, 135d, Changsha), Sichuan (12%, 90%, 1-May, 135d, Chungking), Jiangsu (9.12%, 90%,1-May, 135d, Hangzhou), Hubei (4.32%, 90%, 1-May, 135d, Changsha), Anhui (3.84%, 90%,1-May, 135d, Hangzhou), Fujian (0.96%, 90%, 1-May, 135d, Hangzhou),Yunnan (2.4%, 90%, 1-May, 135d, Kunming), Liaoning 1.92%, 90%,1-May, 135d, Shenyang), Guizhou (1.92%, 90%,1-May, 35d, Chungking), Heilongjiang (1.92%, 90%,1-May, 135d, Harbin), Jilin (1.44%, 90%,1-May, 35d, Shenyang), Henan (1.44%, 90%,1-May, 135d, Heze), Shanghai (0.96%, 90%,1-May, 135d, Hangzhou), Others (4.32%, 90%,1-May, 135d) **Early double:** Hunan (5.46%, 90%, 1-Mar, 120d, Changsha), Hubei (2.34%, 90%, Changsha), Guangdong (4.42%, 90%, Guangzhou), Jiangxi (3.64%, 90%, Changsha), Anhui (1.3%, 90%, Hangzhou), Zhejiang (3.12%, 90%, Hangzhou), Guangxi (3.38%, 90%, Kunming), Fujian (1.56%, 90%, Hangzhou), Others (0.78%, 90%,) **Late double:** Hunan (6.24%, 90%, 1-Aug, 120d, Changsha), Hubei (2.6%,90%, Changsha), Guangdong (4.16%, 90%, 1-Aug, 120d, Guangzhou), Jiangxi (3.64%,90%,1-Aug, 120d, Changsha), Anhui (1.3%, 90%, 1-Aug, 120d, Hangzhou), Zhejiang (3.38%, 90%, 1-Aug, 120d, Hangzhou), Guangxi (2.34%, 90%, 1-Aug, 120d, Kunming), Fujian (1.56%, 90%, 1-Aug, 120d, Hangzhou), Others (0.78%, 90%,1-Aug, 120d)
India	**Khariff:** West Bengal (12.34%, 195000ha, 01-Jun, 150d, Chandbali), Uttar Pradesh (16.43%, 3716000ha, 15-Jun, 120d, Bareilly), Andhra Pradesh (8.70%, 2503000ha, 01-Apr, 180d, Begampet), Punjab (11.08%, 2447000ha, 01-Jul, 120d, Amritsar), Tamil Nadu (8.55%, 1764000ha, 01-May, 150d, Banglore), Bihar (9.40%, 1942000ha, 15-Jun, 120d, Bareilly), Orissa (6.73%, 1375000ha, 01-Jun, 180d, Chandbali), Madhya Pradesh (7.20%, 1282000ha, 15-Jul, 150d, Pendra), Assam (4.10%, 296000ha, 15-Mar, 150d, Guahati), Karnataka (3.38%, 615000ha, 150d, Banglore), Haryana (3.42 %, 1024000ha, 150days,-), Maharashtra (3.25%, 385000ha, 150d,-), Gujarat (1.37%, 371000ha, 150d,-), Kerala (0.83%, 139000ha, 150d,-), Jammu & Kashmir (0.69%, 239000ha, 150d,-), Tripura (0.55%, 150d,-), Manipur (0.50%, 73000ha, 150d,-), Rajasthan (0.29%, 63000ha, 150d,-), Nagaland (0.28%, 65000ha,150d,-), Meghalaya (0.21%, 45000ha, 150d,-), Goa (0.20%, 14000ha, 150d,-), Arunachal Pradesh (0.17%, 34000ha, 150d,-), Himachal Pradesh (0.16%, 51000ha, 150d,-), Mizoram (0.14%, 4000ha, 150d,-), Sikkim (0.03%, 16000ha, 150d,-). *Note: Rainfed area in Khariff season in'000ha: West Bengal 4413, Uttar Pradesh 2104, Andhra Pradesh 172, Punjab 22, Tamil Nadu 164, Bihar 3005, Orissa 2845, Madhya Pradesh 4139, Assam 1980, Karnataka 452, Haryana 4, Maharashtra 1071, Gujarat 282, Kerala 165, Jammu & Kashmir 26, Tripura 202, Manipur 88, Rajasthan 115, Nagaland 81, Meghalaya 60, Goa 43, Arunachal Pradesh 85, Himachal, Pradesh 32 Mizoram 57.* *Total rainfed area = 21606000ha* **Rabi:** West Bengal (36.43%, 1386000ha, 01-Dec, 150d, Chandbali), Uttar Pradesh (0.12%, 6000ha, 01-Dec, 150d, Bareilly), Andhra Pradesh (32.15%, 1232000ha, 01-Jan, 150d, Begampet), Tamil Nadu (9.20%, 318000ha, 01-Nov, 150d, Banglore), Bihar (2.24%, 128000ha, 01-Nov, 150d, Bareilly), Orissa (5.19%, 295000ha, 01-Jan, 150d, Chandbali), Assam (3.92%, 231000ha, 01-Jan, 150d, Guahati), Karnataka (8.21%, 341000ha, 15-Jan,

(Continued)

Appendix A. (Continued)

	150d, Banglore), Maharashtra (0.55%, 33000ha,-), Kerala (1.18%, 59000ha,-), Tripura (0.81%, 55000ha,-), Mizoram (0.01%, 1000 ha,-). *Note: Rabi crop is 100% irrigated in India. Total area under Rabi crop = 4085000ha*
Indonesia	**Main crop:** Java (41.3%,60%,, 15-Nov, 120d, Jakarta and Semarang), S.Sulawesi (8.1%, 60%, 01-Jun, 120d, Manado), N.Sumatra (10.5%, 60%, 01-Aug, 120d, Medan), S.Sumatra (8.4%, 60%,15-Nov, 20d, Palemban), Kalimanthan (5.0%, 60%,15-Nov, 120d, Banjamarsin), Bali and Nusa (6.0%, 60%,15-Nov, 120d, Bali (Denpasa) and Nusa (Kupang)) **Second crop:** Java (17.7%, 100%, 15-May, 120d, Jakarta and Semarang), S.Sulawesi (0.9%, 100%, 01-Nov, 120d, Manado), N.Sumatra (1.1%,100%,01-Apr, 120d,Medan), S.Sumatra (1.1%,100%,15-Jun, 120d, Palemban)
Japan	Tohoku (27%, 100%, 01-Jun, 120d,Akita and Ishinomaki), Kanto Tosan (17%, 100%, 01-Jun, 120d, Niigata), Hokuriku (13%,100%,01-Jun, 120d, Kumagaya), Kyushu (11%, 100%, 01-Jun, 120d, Saga), Chuguko (7%, 100%, 01-Jun, 120d, Fukuyama), Hokkaido (7%, 100%, 01-Jun, 120d, Iwamizawa), Kinki (7%,100%, 01-Jun, 120d, Kyoto),Tokai (6%, 100%, 01-Jun, 120d, Gifu), Shikoku and others (5%, 100%, 01-Jun, 120d, Kochi)
Korea, R.	Inchon (33.33%, 75%, 01-Jun, 120d, Inchon), Taegu (33.33%, 75%, 01-Jun, 120d, Taegu), Mok-poh (33.33%, 75%, 01-Jun, 120d, Mok-poh)
Myanmar	Irrawaddy (23.15%, 15.00%, 01-Jun, 150d, Bassein),Pegu (15.23%, 15.00%, 01-Jun, 150d, Pyinmana), Rangoon (8.60%, 15.00%,01-Jun, 150d, Rangoon), Sagaing (7.88%,15.00%, 1-Jun, 150d, Monywa), Arakan (5.74%, 15.00%, 01-Jun, 150d, Sittwe),Shan (6.12%, 15.00%, 01-Jun, 150d, Mandalay), Mon (4.61%, 15.00%, 01-Jun, 150d, Moulmein),Mandalay (4.29%, 15.00%,01-Jun, 150d, Mandalay), Karen & others (9.38%, 15.00%, 01-Jun, 150d, Molumein), all other regions growing 2nd crop (15.00%,100.00%, 01-Jun, 150d, Rangoon)
Pakistan	Punjab (43%, 100%, 01-Jun, 120d, Lahore), Sind (46%, 100%, 01-Jun, 120d, Hyderabad/ Karachi), Baluchistan (8%, 100%, 01-Jun, 120d, Hyderabad/Dadu), North West Frontier Province (3%, 100%, 01-Jun, 120d, Peshawar)
Philippines	Central Luzon, Southern Tagalog and Ilocos (35%, 77%, 01-Jun, 120d, Manila Airport), Cagyan Valley and Cordillero AR (15%, -%, 01-Jun, 120d, Aparri),Western Vsyas and Central Visyas (9%, -%, 15-Nov, 120d, Ilolo), Western Mindano and Central Mindano (12%, 100%, 15-Nov, 120d, Dipolog), Northern Mindano and Southern Mindano (23%, 100%, 15-Nov, 120d, Hinatuan), Bicol (4%, -%, 01-Jun, 120d, LegaspiEastern Visyas (2%, -%, 15-Nov, 120d, Massin)
Thailand	**Main crop** Northern (23.2%,23%,01-Jun, 120d,ChiangM ai and NakhonS awan),Central (19.2%,23%,01-Jul, 120d,KrungT hep (Bangkok)),North East (33.6%,23%,15-Jun, 120d, Udon Thani and Ubon Ratchathani),South (4%,23%,15-Oct, 120d,Ba nD on) **2nd crop:** Northern (5%, 100%, 15-Feb, 120d, Chiang Mai and Nakhon Sawan), Central (12.8%, 100%, 15-Feb, 120d, KrungT hep (Bangkok)), North East (1.8%, 100%, 15-Feb, 120d,Udon Thani and Ubon Ratchathani), South (0.4%, 100%, 15-Feb, 120d, BanD on)
USA	Arkansas (43.3%, 100%, 01-May, 120d, Memphis), California (13.7%, 100%, 01-Jun, 120d, Sacramento and Frenso), Louisiana (18.8%, 100%, 01-May, 120d, Lafayette),Texas (12.4%, 100%, 01-May, 120d,Victoria), Mississippi (8.6%, 100%, 01-May, 120d, Memphis), Missiouri (3.1%,100%, 01-May, 120d, Memphis)
Viet Nam	**Winter crop** North (16.4%, 85%, 01-Dec, 105d, Hanoi), Central (6.8%, 0%, 01-Dec, 120d, QuiNhon), South (16.8%, 60%, 01-Jan, 120d, Ho Chi Minh (Saigon) Main crop North (11.47%, 85%,15-Jun, 105d, Hanoi), Central (8.14%, 0%, 15-Jun, 120d, QuiNhon), South (17.39%, 60%, 01-Jul, 105d, Ho Chi Minh (Saigon)) **Autumn crop** North (7.13%, 85%, 01-May, 105d, Hanoi), Central (5.06%, 0%, 01-May, 120d, QuiNhon), South (10.81%, 60%, 01-May, 105d, Ho Chi Minh (Saigon))

The K_c values for the initial, mid and end crop development stages are taken as 1.05, 1.2 and 0.6 respectively. The K_c for the end period in China is taken equal to 0.90. For India, the crop water requirement is calculated only for the top 10-states contributing to 85% of national production during Kharif season and 91% during Rabi season. For the remaining regions the national average values for each season are taken. Source: irrigation percentage of Khariff rice is from (Directorate of Rice Development, 2001). All other data were compiled from (USDA, 1994) and various other online national statistical data sources.

Appendix B. Water footprint of national rice production. Period 2000–04.

	Area* ha	Yield* ton/ha	Production* ton/yr	Water footprint of production (Mm^3/yr) Green	Blue	Grey	Total	Percolation (Mm^3/yr)
China	28,670,030	6.2	177,657,605	65,241	86,460	20,786	172,486	139,518
India	43,057,460	2.9	126,503,280	136,258	104,544	14,683	255,486	177,427
Indonesia	11,642,899	4.5	52,014,913	30,309	25,323	6,113	61,744	48,213
Bangladesh	10,641,271	3.5	37,217,379	20,415	21,463	3,831	45,708	41,985
Viet Nam	7,512,160	4.5	33,960,560	10,455	6,888	4,319	21,663	23,661
Thailand	10,038,180	2.7	26,800,046	25,247	14,980	3,112	43,339	33,591
Myanmar	6,431,364	3.5	22,581,828	19,111	8,538	1,125	28,774	24,918
Philippines	4,056,577	3.3	13,322,327	11,246	5,633	1,034	17,914	15,491
Brazil	3,371,562	3.3	11,068,502	8,753	7,411	674	16,838	14,120
Japan	1,706,000	6.4	10,989,200	3,744	4,408	665	8,818	8,317
USA	1,285,671	7.4	9,520,015	2,161	7,951	964	11,076	6,262
Pakistan	2,339,200	3.0	6,910,650	2,909	16,340	611	19,859	11,345
Korea, R	1,045,173	6.5	6,808,450	2,423	2,644	575	5,641	4,320
Egypt	630,353	9.5	5,972,257	3,774	3,487	653	7,913	6,126
Nepal	1,545,156	2.7	4,220,395	2,667	2,464	461	5,592	4,329
Cambodia	2,045,837	2.0	4,165,772	2,632	2,432	455	5,520	4,273
Nigeria	2,211,800	1.4	3,085,600	1,950	1,802	337	4,088	3,165
Sri Lanka	809,552	3.5	2,822,732	1,784	1,648	308	3,740	2,896
Madagascar	1,219,074	2.2	2,715,380	1,716	1,585	297	3,598	2,785
Colombia	499,532	5.1	2,579,150	1,630	1,506	282	3,417	2,646
Iran	577,372	4.2	2,464,653	1,557	1,439	269	3,266	2,528
Laos	746,177	3.2	2,371,400	1,498	1,385	259	3,142	2,433
Malaysia	680,660	3.2	2,190,829	1,384	1,279	239	2,903	2,247
Korea, DPR	571,371	3.7	2,110,040	1,333	1,232	231	2,796	2,164
Peru	301,409	6.6	2,003,010	1,266	1,170	219	2,654	2,055
Ecuador	367,290	3.8	1,419,705	897	829	155	1,881	1,456
Italy	221,009	6.1	1,359,921	859	794	149	1,802	1,395
Guinea	649,437	1.7	1,123,543	710	656	123	1,489	1,153
Uruguay	168,635	6.3	1,069,425	676	624	117	1,417	1,097
Australia	113,307	8.7	985,385	623	575	108	1,306	1,011
Tanzania	498,186	1.7	861,572	544	503	94	1,142	884
Argentina	153,400	5.6	852,764	539	498	93	1,130	875
Spain	117,248	7.3	852,050	538	497	93	1,129	874
Mali	407,607	2.0	808,799	511	472	88	1,072	830
Venezuela	152,577	4.9	751,797	475	439	82	996	771
Côte d'Ivoire	340,713	1.9	648,855	410	379	71	860	666
Dominican Republic	136,683	4.7	643,747	407	376	70	853	660
Cuba	188,867	3.2	610,100	386	356	67	808	626
Russia	141,600	3.5	498,952	315	291	55	661	512
Guyana	118,627	4.1	487,027	308	284	53	645	500
Turkey	62,400	6.2	386,400	244	226	42	512	396
Sierra Leone	376,643	1.0	381,767	241	223	42	506	392
Afghanistan	145,200	2.4	357,400	226	209	39	474	367
Bolivia	145,134	2.3	329,117	208	192	36	436	338
Congo, DR	426,004	0.8	321,633	203	188	35	426	330
Nicaragua	87,129	3.2	277,059	175	162	30	367	284
Mexico	62,032	4.4	271,416	171	158	30	360	278
Panama	119,921	2.2	264,672	167	155	29	351	272
Ghana	122,088	2.1	256,783	162	150	28	340	263
Kazakhstan	73,367	3.2	232,256	147	136	25	308	238

(Continued)

Appendix B. (Continued)

	Area* ha	Yield* ton/ha	Production* ton/yr	Water footprint of production (Mm^3/yr) Green	Blue	Grey	Total	Percolation (Mm^3/yr)
Costa Rica	57,875	3.6	210,747	133	123	23	279	216
Senegal	83,761	2.4	203,045	128	119	22	269	208
Uzbekistan	84,562	2.2	182,526	115	107	20	242	187
Suriname	46,854	3.8	176,061	111	103	19	233	181
Greece	22,119	7.3	161,522	102	94	18	214	166
Iraq	83,500	2.1	155,600	98	91	17	206	160
Mozambique	173,892	0.9	153,901	97	90	17	204	158
Portugal	25,051	5.8	146,301	92	85	16	194	150
Chile	27,086	5.0	136,072	86	79	15	180	140
Liberia	126,700	1.0	129,680	82	76	14	172	133
Uganda	81,400	1.5	119,200	75	70	13	158	122
Haiti	53,340	2.1	114,400	72	67	12	152	117
Chad	93,877	1.2	111,356	70	65	12	148	114
Paraguay	28,252	3.9	109,490	69	64	12	145	112
France	19,348	5.6	109,166	69	64	12	145	112
Burkina Faso	48,549	2.0	94,411	60	55	10	125	97
Guinea-Bissau	68,314	1.3	91,315	58	53	10	121	94
Ukraine	21,330	3.7	79,680	50	47	9	106	82
Malawi	49,332	1.6	78,937	50	46	9	105	81
Mauritania	17,450	4.4	75,390	48	44	8	100	77
Turkmenistan	47,800	1.6	73,160	46	43	8	97	75
Niger	23,132	3.0	70,376	44	41	8	93	72
Togo	31,482	2.1	64,832	41	38	7	86	67
Burundi	18,840	3.2	60,207	38	35	7	80	62
Benin	25,550	2.3	57,838	37	34	6	77	59
Timor-Leste	34,710	1.8	57,087	36	33	6	76	59
Tajikistan	17,154	3.3	56,563	36	33	6	75	58
Cameroon	32,168	1.9	52,993	33	31	6	70	54
Kenya	12,817	3.6	46,429	29	27	5	62	48
Bhutan	21,310	2.1	44,485	28	26	5	59	46
Guatemala	14,956	2.6	39,557	25	23	4	52	41
El Salvador	5,325	6.2	32,611	21	19	4	43	33
Gambia	13,080	2.1	28,050	18	16	3	37	29
Morocco	5,460	5.1	27,542	17	16	3	36	28
Central Afr. Rep.	14,500	1.9	27,480	17	16	3	36	28
French Guiana	8,042	3.1	24,511	15	14	3	32	25
Rwanda	7,111	3.3	24,464	15	14	3	32	25
Bulgaria	4,587	4.6	21,044	13	12	2	28	22
Kyrgyzstan	6,126	3.0	18,609	12	11	2	25	19
Comoros	14,000	1.2	17,000	11	10	2	23	17
Azerbaijan	3,545	4.6	16,664	11	10	2	22	17
Sudan	6,388	2.3	15,750	10	9	2	21	16
Honduras	4,620	3.2	15,272	10	9	2	20	16
Zambia	11,113	1.3	14,354	9	8	2	19	15
Fiji	6,055	2.3	14,099	9	8	2	19	14
Ethiopia	7,593	1.8	13,882	9	8	2	18	14
Macedonia	2,627	4.8	12,582	8	7	1	17	13
Belize	4,018	2.9	11,367	7	7	1	15	12
Hungary	2,608	3.8	9,904	6	6	1	13	10
Somalia	1,604	5.9	9,600	6	6	1	13	10
Angola	6,196	1.3	7,378	5	4	1	10	8

Appendix B. (Continued)

	Area* ha	Yield* ton/ha	Production* ton/yr	Water footprint of production (Mm^3/yr) Green	Blue	Grey	Total	Percolation (Mm^3/yr)
Solomon Islands	1,300	3.9	5,100	3	3	1	7	5
Trinidad & Tbg.	1,154	2.9	3,368	2.13	1.97	0.37	4.46	3.45
South Africa	1,380	2.3	3,160	2.00	1.85	0.35	4.19	3.24
Romania	889	2.3	2,183	1.38	1.27	0.24	2.89	2.24
Congo	1,959	0.7	1,299	0.82	0.76	0.14	1.72	1.33
Gabon	500	2.0	1,000	0.63	0.58	0.11	1.33	1.03
Papua New Guinea	390	2.0	780	0.49	0.46	0.09	1.03	0.80
Zimbabwe	266	2.3	620	0.39	0.36	0.07	0.82	0.64
Brunei Darussalam	579	0.7	438	0.28	0.26	0.05	0.58	0.45
Algeria	200	1.5	300	0.19	0.18	0.03	0.40	0.31
Swaziland	50	3.4	170	0.11	0.10	0.02	0.23	0.17
Micronesia	80	1.1	90	0.06	0.05	0.01	0.12	0.09
Réunion	40	2.0	80	0.05	0.05	0.01	0.11	0.08
Jamaica	14	1.1	16	0.01	0.01	0.00	0.02	0.02
Total	150,666,851	4.49**	591,751,209	373,907	345,512	64,655	784,073	607,019

* *Source: FAO (2009)*
** *Weighted average, calculated based on production per country.*

Appendix C. Water footprint of national rice consumption. Period 2000–04.

	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total water footprint (Mm^3/yr)*			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
India	133,493	102,423	14,385	250,301	1	3	0	4	133,494	102,425	14,385	250,305
China	64,754	85,812	20,630	171,195	400	238	50	688	65,154	86,050	20,680	171,884
Indonesia	30,301	25,316	6,111	61,727	797	689	151	1,637	31,097	26,005	6,262	63,364
Bangladesh	20,414	21,462	3,831	45,707	146	112	16	273	20,560	21,574	3,846	45,980
Thailand	19,639	11,653	2,421	33,713	1	1	0	2	19,640	11,654	2,421	33,714
Myanmar	18,989	8,483	1,118	28,591	–	–	–	–	18,989	8,483	1,118	28,591
Viet nam	9,860	6,496	4,074	20,430	–	–	–	–	9,860	6,496	4,074	20,430
Philippines	11,246	5,633	1,034	17,914	490	386	103	979	11,736	6,020	1,137	18,893
Brazil	8,735	7,396	673	16,804	451	474	84	1,008	9,186	7,869	757	17,812
Pakistan	2,480	13,935	521	16,936	–	–	–	–	2,480	13,935	521	16,936
Japan	3,724	4,386	662	8,772	360	537	86	983	4,084	4,923	748	9,755
USA	1,598	5,554	679	7,831	326	225	41	591	1,924	5,779	719	8,422
Egypt	3,467	3,203	599	7,269	–	–	–	–	3,467	3,203	599	7,269
Nigeria	1,949	1,801	337	4,088	1,528	1,204	211	2,943	3,478	3,005	548	7,031
Korea R.	2,409	2,628	572	5,609	82	103	21	205	2,491	2,732	592	5,814
Nepal	2,667	2,464	461	5,592	15	14	2	31	2,682	2,478	463	5,623
Cambodia	2,628	2,428	454	5,511	46	31	6	83	2,674	2,459	461	5,594
Iran	1,552	1,434	268	3,254	676	726	98	1,500	2,227	2,160	367	4,754
Madagascar	1,715	1,585	297	3,597	114	280	21	414	1,829	1,865	318	4,012
Sri lanka	1,782	1,647	308	3,737	80	124	10	214	1,862	1,771	318	3,951
Malaysia	1,366	1,262	236	2,865	417	366	70	852	1,783	1,628	306	3,717
Colombia	1,629	1,506	282	3,417	73	65	12	150	1,703	1,570	294	3,567
Laos	1,498	1,385	259	3,142	–	–	–	–	1,498	1,385	259	3,142
Peru	1,266	1,170	219	2,654	38	42	7	87	1,304	1,212	226	2,741
Ecuador	863	797	149	1,809	1	1	0	3	864	798	149	1,812
Guinea	710	656	123	1,489	90	112	20	223	800	768	143	1,711
Senegal	128	118	22	269	756	482	107	1,344	884	600	129	1,613
Saudi arabia	–	–	–	–	650	694	82	1,426	650	694	82	1,426
Tanzania	541	500	94	1,135	90	95	21	207	631	595	115	1,341
South africa	2	2	0	4	701	509	88	1,298	703	511	89	1,302
Mexico	171	158	30	359	160	579	70	809	331	737	100	1,168
Russian fed	304	282	53	639	231	224	58	513	535	505	111	1,152
Mali	511	472	88	1,072	19	15	4	38	530	488	92	1,110

Turkey	244	225	42	511	172	263	42	477	416	488	84	988
Venezuela	456	421	79	956	4	15	2	21	460	437	81	977
Cuba	385	356	67	808	72	71	26	169	457	428	92	977
Italy	403	380	69	853	39	44	6	89	442	424	75	941
Cote divoire	408	377	71	856	–	–	–	–	408	377	71	856
Australia	366	339	62	767	41	40	5	87	407	379	68	854
Dominican R	403	372	70	845	3	3	1	6	406	375	70	851
UK	–	–	–	–	331	423	55	808	331	423	55	808
Spain	321	301	56	678	52	57	9	118	373	358	65	796
France	57	53	10	120	306	302	49	658	364	356	59	778
Ghana	162	149	28	339	213	185	37	435	375	334	65	774
Argentina	358	331	62	750	8	7	1	16	365	338	63	766
Hong kong	–	–	–	–	367	235	48	651	367	235	48	651
Singapore	–	–	–	–	346	219	49	614	346	219	49	614
Kenya	29	27	5	62	98	349	20	467	127	376	25	529
Uruguay	248	229	43	519	0	0	0	1	248	229	43	520
Afghanistan	224	207	39	470	–	–	–	–	224	207	39	470
Bolivia	207	191	36	434	5	5	1	11	212	196	37	445
Nicaragua	174	161	30	366	15	42	5	62	189	203	36	428
Congo DR	203	188	35	426	–	–	–	–	203	188	35	426
Guyana	193	178	33	405	0	0	0	0	193	178	33	405
Costa rica	130	121	23	273	26	94	11	131	156	215	34	405
Mozambique	95	89	16	200	56	127	9	192	151	215	26	392
Canada	–	–	–	–	118	219	28	365	118	219	28	365
Panama	160	148	28	335	3	10	1	14	163	158	29	349
Germany	–	–	–	–	140	178	26	344	140	178	26	344
Portugal	89	82	15	186	75	69	13	156	163	150	28	342
Oman	–	–	–	–	83	241	14	339	83	241	14	339
Kazakstan	130	120	22	272	1	2	0	4	131	122	23	276
Niger	44	41	8	93	69	94	13	176	113	135	21	269
Burkina faso	60	55	10	125	67	56	10	133	127	111	20	258
Belgium	–	–	–	–	108	117	18	243	108	117	18	243
Uzbekistan	115	106	20	241	–	–	–	–	115	106	20	241
Uganda	75	69	13	157	24	53	7	83	99	122	20	241
Chile	85	79	15	179	30	24	4	58	115	103	19	237
Iraq	92	85	16	192	–	–	–	–	92	85	16	192

(*Continued*)

Appendix C. (Continued)

	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total water footprint (Mm^3/yr)*			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Jordan	–	–	–	–	79	91	15	184	79	91	15	184
Mauritius	–	–	–	–	51	119	8	179	51	119	8	179
Suriname	85	78	15	178	–	–	–	–	85	78	15	178
Liberia	82	75	14	171	–	–	–	–	82	75	14	171
Poland	–	–	–	–	69	86	14	170	69	86	14	170
Benin	36	33	6	76	47	39	7	93	83	73	13	169
Togo	39	36	7	82	37	38	7	81	76	74	13	164
Haiti	72	67	12	151	–	–	–	–	72	67	12	151
Ukraine	50	46	9	105	24	19	4	46	74	65	13	151
Yemen	–	–	–	–	71	62	9	142	71	62	9	142
Greece	60	56	10	126	7	7	1	15	67	63	12	141
Qatar	–	–	–	–	31	103	5	139	31	103	5	139
Kuwait	–	–	–	–	57	74	7	138	57	74	7	138
Gambia	18	16	3	37	50	42	8	99	68	58	11	137
Romania	1	1	0	3	61	60	12	133	62	62	12	136
Paraguay	63	58	11	131	2	1	0	3	64	59	11	134
El salvador	20	19	4	43	19	62	8	89	39	81	11	131
Guatemala	25	23	4	52	16	52	6	75	41	75	11	127
Switz.liecht	–	–	–	–	57	51	8	116	57	51	8	116
Malawi	50	46	9	104	3	4	0	7	53	50	9	112
Gabon	1	1	0	1	63	38	8	109	64	38	9	111
Taiwan (poc)	–	–	–	–	40	63	8	110	40	63	8	110
Turkmenistan	46	43	8	97	3	3	1	7	50	46	9	104
Hungary	6	6	1	13	36	34	6	76	42	40	7	89
Algeria	0	0	0	0	41	37	10	87	41	37	10	87
Netherlands	–	–	–	–	20	63	4	87	20	63	4	87
Sweden	–	–	–	–	40	38	6	85	40	38	6	85
Czech R.	–	–	–	–	37	38	7	83	37	38	7	83
Burundi	38	35	7	80	0	0	0	0	38	35	7	80
Bahrain	–	–	–	–	19	57	3	80	19	57	3	80
Israel	–	–	–	–	37	28	6	70	37	28	6	70
Cameroon	33	31	6	70	–	–	–	–	33	31	6	70
Jamaica	0	0	0	0	27	35	6	68	27	35	6	68
Tajikistan	31	29	5	66	–	–	–	–	31	29	5	66

Lebanon	–	–	–	–	30	29	5	65	30	29	5	65
New zealand	–	–	–	–	29	29	4	62	29	29	4	62
Bhutan	28	26	5	59	–	–	–	–	28	26	5	59
Bulgaria	13	12	2	27	13	15	3	31	26	26	5	58
Honduras	9	9	2	19	7	26	3	37	16	35	5	56
Belarus	–	–	–	–	24	26	4	54	24	26	4	54
Azerbaijan	10	10	2	22	14	15	2	32	25	25	4	54
Fiji	9	8	2	19	19	13	3	35	28	21	4	54
Slovakia	–	–	–	–	24	25	4	53	24	25	4	53
Rwanda	15	14	3	32	6	11	1	18	21	25	4	50
Macau	–	–	–	–	27	17	4	47	27	17	4	47
Denmark	–	–	–	–	22	20	4	46	22	20	4	46
Austria	–	–	–	–	22	20	4	46	22	20	4	46
Trinidad tbg	2	2	0	4	16	19	3	37	18	20	3	41
Cent.Afr. R.	17	16	3	36	1	2	0	3	19	18	3	40
Finland	–	–	–	–	19	17	3	40	19	17	3	40
Morocco	17	16	3	36	1	1	0	3	19	17	3	39
Ethiopia	9	8	2	18	8	9	1	18	17	17	3	36
Norway	–	–	–	–	17	15	2	34	17	15	2	34
Sudan	10	9	2	21	6	5	1	12	16	15	3	33
Zambia	9	8	2	19	7	6	1	14	16	14	3	33
Maldives	–	–	–	–	16	15	2	33	16	15	2	33
Albania	–	–	–	–	14	14	3	31	14	14	3	31
Kyrgyzstan	12	11	2	25	1	1	0	3	13	12	2	27
Tunisia	–	–	–	–	15	9	2	26	15	9	2	26
Brunei dar.	0	0	0	1	11	7	1	20	12	7	1	20
Lithuania	–	–	–	–	9	9	1	20	9	9	1	20
Ireland	–	–	–	–	8	9	2	18	8	9	2	18
Armenia	–	–	–	–	7	8	1	17	7	8	1	17
Macedonia, tfyr	7	7	1	16	0	0	0	1	8	7	1	16
Fr.polynesia	–	–	–	–	8	7	1	16	8	7	1	16
Croatia	–	–	–	–	8	7	1	16	8	7	1	16
Moldova rep.	–	–	–	–	6	8	1	15	6	8	1	15
Belize	7	7	1	15	0	0	0	0	7	7	1	15
Zimbabwe	0	0	0	1	7	6	1	14	8	6	1	15
Others	5	5	1	11	57	74	13	143	62	79	13	154
Grand total	360,336	331,511	62,360	754,208	13,570	14,000	2,295	29,865	373,907	345,512	64,655	784,073

* Note: It is the total water footprint of a nation related to rice consumption. It does not include water losses as a result of percolation and left over soil moisture in the rice fields.

Appendix D. Virtual water fluxes related to the international trade in rice products. Period 2000–04.

Countries	Gross virtual water import (Mm^3/yr)				Gross virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Afghanistan					1.8	1.6	0.3	3.7	−1.8	−1.6	−0.3	−3.7
Albania	14.2	14.0	2.8	30.9					14.2	14.0	2.8	30.9
Algeria	40.9	36.6	9.6	87.1	0.0	0.0	0.0	0.0	40.9	36.6	9.6	87.1
Andorra	0.3	0.3	0.0	0.6	0.2	0.1	0.0	0.3	0.1	0.1	0.0	0.3
Anguilla	0.1	0.3	0.0	0.4					0.1	0.3	0.0	0.4
Antigua Barbados	0.2	0.2	0.0	0.4					0.2	0.2	0.0	0.4
Argentina	11.3	10.7	1.5	23.5	184.9	170.9	32.0	387.8	−173.6	−160.1	−30.5	−364.2
Armenia	7.3	8.2	1.3	16.9					7.3	8.2	1.3	16.9
Aruba					9.8	9.0	1.7	20.5	−9.8	−9.0	−1.7	−20.5
Australia	70.4	68.0	9.4	147.7	285.7	264.0	49.4	599.2	−215.3	−196.0	−40.0	−451.4
Austria	23.0	21.5	3.9	48.4	1.3	1.2	0.2	2.8	21.6	20.3	3.7	45.5
Azerbaijan	14.5	15.3	2.2	32.0	0.2	0.2	0.0	0.4	14.3	15.1	2.2	31.6
Bahamas	0.9	3.4	0.4	4.7	0.9	0.8	0.1	1.8	0.1	2.6	0.3	2.9
Bahrain	19.6	57.7	3.1	80.3	0.3	0.2	0.0	0.5	19.3	57.4	3.0	79.8
Bangladesh	145.6	111.8	15.7	273.1	0.5	0.6	0.1	1.2	145.0	111.2	15.6	271.8
Barbados	2.1	6.1	0.8	9.0	0.0	0.0	0.0	0.0	2.1	6.1	0.8	8.9
Belarus	24.2	25.8	4.2	54.2					24.2	25.8	4.2	54.2
Belgium	188.5	191.5	32.4	412.3	80.9	74.8	14.0	169.7	107.6	116.7	18.4	242.6
Belize	0.0	0.1	0.0	0.1	0.2	0.1	0.0	0.3	−0.1	0.0	0.0	−0.2
Benin	47.0	39.4	6.9	93.3	0.6	0.6	0.1	1.3	46.3	38.8	6.8	91.9
Bhutan					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bolivia	5.3	5.1	0.9	11.3	1.2	1.1	0.2	2.6	4.0	4.0	0.7	8.7
Bosnia Herzg	1.6	1.6	0.3	3.5					1.6	1.6	0.3	3.5
Botswana	4.4	4.1	0.8	9.3					4.4	4.1	0.8	9.3
Br.Virgin Island					1.0	0.9	0.2	2.1	−1.0	−0.9	−0.2	−2.1
Brazil	451.7	474.5	84.0	1010.2	18.8	15.9	1.4	36.1	432.9	458.6	82.6	974.1
Brunei	11.6	7.1	1.5	20.2	0.2	0.2	0.0	0.4	11.4	7.0	1.4	19.8
Bulgaria	13.9	15.2	3.1	32.2	1.2	1.1	0.2	2.5	12.7	14.1	2.9	29.7
Burkina Faso	67.5	55.7	10.2	133.4	0.3	0.2	0.0	0.5	67.2	55.4	10.2	132.8
Burundi	0.0	0.0	0.0	0.1					0.0	0.0	0.0	0.1
Cambodia	46.1	30.8	6.1	83.0	4.2	3.9	0.7	8.8	41.9	26.9	5.4	74.1
Cameroon					0.1	0.1	0.0	0.1	−0.1	−0.1	0.0	−0.1
Canada	122.3	223.6	29.0	374.9	4.5	4.2	0.8	9.5	117.8	219.4	28.2	365.4
Cape Verde	5.1	3.5	1.5	10.1					5.1	3.5	1.5	10.1
Cayman Islands					0.2	0.1	0.0	0.3	−0.2	−0.1	0.0	−0.3

Cent.Afr. R.	1.4	1.8	0.2	3.4					1.4	1.8	0.2	3.4
Chile	30.2	24.0	4.5	58.6	1.0	0.9	0.2	2.1	29.2	23.1	4.3	56.5
China	403.3	239.9	50.4	693.7	490.2	649.7	156.2	1296.1	−87.0	−409.8	−105.7	−602.5
Colombia	73.5	64.7	12.1	150.3	0.3	0.3	0.1	0.6	73.2	64.4	12.0	149.7
Costa Rica	26.4	95.6	11.6	133.6	3.9	3.6	0.7	8.2	22.5	91.9	10.9	125.3
Cote Divoire					1.7	1.5	0.3	3.5	−1.7	−1.5	−0.3	−3.5
Croatia	8.1	7.1	1.4	16.5	0.4	0.4	0.1	0.8	7.7	6.7	1.3	15.7
Cuba	71.6	71.4	25.5	168.5	0.0	0.0	0.0	0.1	71.5	71.4	25.5	168.5
Cyprus	3.9	3.8	0.6	8.3	11.4	10.5	2.0	23.8	−7.4	−6.7	−1.3	−15.5
Czech R.	40.9	41.8	7.5	90.3	3.6	3.3	0.6	7.6	37.3	38.4	6.9	82.7
Denmark	25.7	23.4	4.4	53.5	3.4	3.2	0.6	7.2	22.2	20.3	3.8	46.3
Djibouti					1.9	1.8	0.3	4.1	−1.9	−1.8	−0.3	−4.1
Dominica	0.8	0.7	0.1	1.6					0.8	0.7	0.1	1.6
Dominican R.	2.6	3.0	0.5	6.2	3.9	3.6	0.7	8.1	−1.2	−0.6	−0.2	−2.0
Ecuador	1.3	1.2	0.2	2.7	34.3	31.7	5.9	72.0	−33.0	−30.5	−5.7	−69.3
Egypt					307.0	283.7	53.1	643.9	−307.0	−283.7	−53.1	−643.9
El Salvador	19.7	62.3	7.8	89.7	0.8	0.7	0.1	1.6	18.9	61.6	7.6	88.1
Eritrea	0.5	0.5	0.1	1.1					0.5	0.5	0.1	1.1
Estonia	2.3	3.7	0.4	6.4					2.3	3.7	0.4	6.4
Ethiopia	8.0	9.0	1.2	18.2	0.1	0.1	0.0	0.2	7.9	8.9	1.1	18.0
Fiji	19.5	12.8	2.6	34.9					19.5	12.8	2.6	34.9
Finland	19.9	18.0	3.4	41.3	0.8	0.7	0.1	1.6	19.1	17.3	3.2	39.7
Fr.Polynesia	7.8	6.7	1.3	15.8					7.8	6.7	1.3	15.8
France	369.7	361.4	59.9	791.0	75.2	69.5	13.0	157.6	294.6	291.9	46.9	633.4
Gabon	63.1	37.9	8.4	109.4	0.0	0.0	0.0	0.1	63.0	37.8	8.4	109.3
Gambia	49.9	41.6	8.0	99.5	0.1	0.1	0.0	0.2	49.8	41.5	8.0	99.4
Georgia	2.5	1.7	0.4	4.6					2.5	1.7	0.4	4.6
Germany	205.0	238.4	37.7	481.0	65.2	60.2	11.3	136.7	139.8	178.1	26.4	344.4
Ghana	214.2	186.0	37.0	437.2	1.6	1.4	0.3	3.3	212.6	184.5	36.7	433.9
Greece	11.4	11.8	1.9	25.1	46.7	43.1	8.1	97.8	−35.3	−31.4	−6.1	−72.8
Grenada	0.9	1.1	0.2	2.2					0.9	1.1	0.2	2.2
Guatemala	16.2	52.7	6.5	75.5	0.6	0.5	0.1	1.2	15.6	52.2	6.4	74.2
Guinea	90.1	112.2	20.4	222.7					90.1	112.2	20.4	222.7
Guyana	0.1	0.1	0.0	0.1	114.6	105.9	19.8	240.4	−114.6	−105.9	−19.8	−240.3
Haiti					0.1	0.1	0.0	0.2	−0.1	−0.1	0.0	−0.2
Honduras	7.7	27.3	3.3	38.4	1.4	1.3	0.2	3.0	6.3	26.0	3.1	35.4
Hong Kong	368.5	236.9	48.8	654.2	1.3	1.8	0.4	3.5	367.1	235.2	48.4	650.7
Hungary	36.1	34.3	6.2	76.6	0.1	0.1	0.0	0.2	36.0	34.3	6.1	76.4
Iceland	0.7	0.8	0.1	1.6	0.0	0.0	0.0	0.1	0.6	0.8	0.1	1.5

(*Continued*)

Appendix D. (Continued)

Countries	Gross virtual water import (Mm^3/yr)				Gross virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
India	1.3	2.7	0.4	4.4	2765.4	2121.7	298.0	5185.1	−2764.0	−2119.0	−297.6	−5180.7
Indonesia	796.9	689.2	151.2	1637.3	8.6	7.2	1.7	17.5	788.3	682.0	149.5	1619.8
Iran	678.0	729.0	98.8	1505.9	8.3	7.7	1.4	17.4	669.8	721.4	97.4	1488.5
Iraq					6.8	6.3	1.2	14.2	−6.8	−6.3	−1.2	−14.2
Ireland	10.4	10.8	1.9	23.1	2.3	2.1	0.4	4.7	8.1	8.7	1.5	18.4
Israel	37.0	27.7	5.6	70.3	0.0	0.0	0.0	0.0	37.0	27.7	5.6	70.3
Italy	82.5	91.7	12.8	187.1	499.6	461.7	86.4	1047.7	−417.1	−369.9	−73.6	−860.6
Jamaica	27.3	35.2	5.7	68.2	0.0	0.0	0.0	0.0	27.3	35.2	5.7	68.2
Japan	361.9	539.6	86.9	988.3	21.6	25.5	3.8	51.0	340.2	514.1	83.0	937.3
Jordan	80.3	91.9	15.0	187.1	1.3	1.2	0.2	2.8	78.9	90.7	14.7	184.3
Kazakstan	1.7	2.1	0.5	4.2	17.4	16.1	3.0	36.4	−15.7	−13.9	−2.5	−32.2
Kenya	98.1	349.0	20.1	467.2	0.0	0.0	0.0	0.1	98.0	349.0	20.1	467.1
Korea Rep.	82.1	103.7	20.8	206.6	14.5	15.8	3.4	33.7	67.7	87.9	17.3	173.0
Kuwait	57.1	74.6	7.0	138.6	0.2	0.2	0.0	0.5	56.8	74.4	6.9	138.1
Kyrgyzstan	1.0	1.4	0.3	2.7					1.0	1.4	0.3	2.7
Latvia	4.9	5.8	0.9	11.6	3.1	2.9	0.5	6.5	1.8	2.9	0.3	5.1
Lebanon	30.1	29.5	5.1	64.7	0.1	0.1	0.0	0.2	30.1	29.4	5.1	64.6
Liberia					0.3	0.3	0.1	0.6	−0.3	−0.3	−0.1	−0.6
Lithuania	9.2	9.6	1.4	20.3	0.3	0.3	0.1	0.6	8.9	9.4	1.4	19.6
Luxembourg	1.1	1.0	0.2	2.3	0.0	0.0	0.0	0.1	1.1	1.0	0.2	2.2
Macau	27.0	16.7	3.5	47.2					27.0	16.7	3.5	47.2
Macedonia	0.4	0.4	0.1	0.9	0.5	0.5	0.1	1.1	−0.1	−0.1	0.0	−0.2
Madagascar	113.6	279.7	21.3	414.5	0.3	0.3	0.0	0.6	113.3	279.4	21.2	413.9
Malawi	2.8	4.0	0.5	7.3	0.1	0.1	0.0	0.2	2.7	3.9	0.4	7.0
Malaysia	422.2	371.0	70.5	863.6	23.4	21.7	4.1	49.1	398.7	349.3	66.5	814.5
Maldives	16.3	14.5	1.9	32.7					16.3	14.5	1.9	32.7
Mali	19.3	15.5	3.6	38.4					19.3	15.5	3.6	38.4
Malta	1.2	1.3	0.2	2.6					1.2	1.3	0.2	2.6
Mauritius	51.3	119.3	8.3	178.8					51.3	119.3	8.3	178.8
Mexico	160.1	579.5	70.5	810.0	0.6	0.6	0.1	1.3	159.4	578.9	70.4	808.7
Moldova Rep.	5.8	7.7	1.4	14.9					5.8	7.7	1.4	14.9
Mongolia	3.3	4.2	1.0	8.5	0.3	0.2	0.0	0.5	3.1	4.0	0.9	7.9
Montserrat	0.0	0.1	0.0	0.2					0.0	0.1	0.0	0.2
Morocco	1.1	1.4	0.2	2.7					1.1	1.4	0.2	2.7
Mozambique	57.3	128.5	9.4	195.2	3.4	3.2	0.6	7.2	53.9	125.3	8.8	188.1
Myanmar					121.5	54.3	7.2	182.9	−121.5	−54.3	−7.2	−182.9

N.Caledonia	6.4	5.4	1.0	12.8					6.4	5.4	1.0	12.8
Namibia	4.0	4.5	0.7	9.3					4.0	4.5	0.7	9.3
Nepal	15.4	13.9	1.9	31.2	0.2	0.1	0.0	0.3	15.2	13.8	1.8	30.8
Neth.Antiles					7.6	7.0	1.3	15.9	−7.6	−7.0	−1.3	−15.9
Netherlands	154.2	187.0	27.0	368.3	133.9	123.8	23.2	280.9	20.3	63.2	3.9	87.4
New Zealand	29.1	28.6	4.5	62.2	0.1	0.1	0.0	0.1	29.1	28.5	4.5	62.1
Nicaragua	15.0	42.2	5.4	62.6	0.8	0.8	0.1	1.7	14.2	41.4	5.3	60.9
Niger	69.0	93.9	13.1	175.9					69.0	93.9	13.1	175.9
Nigeria	1528.5	1203.9	211.4	2943.8	0.4	0.3	0.1	0.8	1528.1	1203.6	211.3	2943.0
Norway	18.7	16.3	2.6	37.6	1.9	1.8	0.3	4.1	16.7	14.5	2.3	33.5
Oman	83.3	241.5	14.4	339.2	0.3	0.3	0.1	0.6	83.0	241.2	14.3	338.5
Pakistan					428.1	2405.2	89.9	2923.2	−428.1	−2405.2	−89.9	−2923.2
Panama	2.8	10.2	1.2	14.3	7.6	7.0	1.3	15.9	−4.7	3.2	−0.1	−1.6
Paraguay	1.7	1.5	0.2	3.3	6.8	6.3	1.2	14.3	−5.1	−4.8	−1.0	−11.0
Peru	38.0	42.2	7.3	87.5					38.0	42.2	7.3	87.5
Philippines	489.8	386.4	103.0	979.2	0.1	0.1	0.0	0.2	489.7	386.3	103.0	979.0
Poland	69.9	86.9	13.8	170.6	0.5	0.5	0.1	1.1	69.4	86.4	13.7	169.5
Portugal	77.9	71.7	13.4	163.0	7.3	6.7	1.3	15.2	70.7	65.0	12.1	147.8
Qatar	31.1	103.3	5.2	139.6	0.1	0.1	0.0	0.2	31.0	103.2	5.2	139.4
Romania	61.2	60.6	12.0	133.8	0.2	0.2	0.0	0.5	61.0	60.4	11.9	133.3
Russia	238.8	231.7	59.8	530.3	19.0	17.6	3.3	39.9	219.8	214.1	56.5	490.4
Rwanda	5.7	11.0	1.3	18.0					5.7	11.0	1.3	18.0
S.Vincent-Gr	2.8	7.5	1.0	11.2	2.5	2.3	0.4	5.3	0.3	5.2	0.5	5.9
Samoa	1.3	1.7	0.4	3.4					1.3	1.7	0.4	3.4
Sao Tome Prn	0.6	0.7	0.1	1.4					0.6	0.7	0.1	1.4
Saudi Arabia	651.3	695.4	82.0	1428.7	1.3	1.2	0.2	2.8	650.0	694.2	81.8	1425.9
Senegal	756.7	482.3	106.8	1345.7	0.8	0.8	0.1	1.7	755.8	481.6	106.6	1344.0
Serbia, Mtneg	4.0	3.6	0.7	8.3					4.0	3.6	0.7	8.3
Seychelles	5.0	4.0	0.6	9.7					5.0	4.0	0.6	9.7
Singapore	383.0	252.5	55.3	690.7	36.5	33.7	6.3	76.5	346.5	218.8	49.0	614.2
Slovakia	24.0	24.9	4.5	53.4	0.1	0.1	0.0	0.3	23.8	24.8	4.5	53.1
Slovenia	6.0	5.8	1.1	12.9	1.6	1.5	0.3	3.4	4.4	4.2	0.8	9.4
Somalia					1.0	0.9	0.2	2.0	−1.0	−0.9	−0.2	−2.0
South Africa	724.5	531.1	92.4	1347.9	23.7	21.9	4.1	49.8	700.8	509.1	88.3	1298.2
Spain	87.0	94.4	15.8	197.2	252.7	233.5	43.7	529.9	−165.7	−139.1	−27.9	−332.6

(*Continued*)

Appendix D. (Continued)

Countries	Gross virtual water import (Mm^3/yr)				Gross virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Sri Lanka	79.7	124.1	10.2	214.0	1.5	1.4	0.3	3.2	78.1	122.7	9.9	210.8
St.Kitts Nev	0.3	1.0	0.1	1.4					0.3	1.0	0.1	1.4
St.Lucia	2.0	2.0	0.4	4.4	0.0	0.0	0.0	0.0	2.0	2.0	0.4	4.3
Sudan	5.7	5.5	1.0	12.2					5.7	5.5	1.0	12.2
Suriname					26.5	24.5	4.6	55.6	−26.5	−24.5	−4.6	−55.6
Swaziland	6.1	5.7	1.1	12.9					6.1	5.7	1.1	12.9
Sweden	41.3	38.9	6.3	86.6	0.8	0.8	0.1	1.7	40.5	38.2	6.2	84.9
Switzerland-Liecht.	72.7	65.8	10.5	149.1	15.6	14.4	2.7	32.7	57.2	51.4	7.8	116.4
Syria	140.8	117.7	22.2	280.7	261.9	242.0	45.3	549.2	−121.1	−124.3	−23.1	−268.5
Taiwan, PoC	49.7	76.4	11.3	137.4	10.2	13.5	3.2	27.0	39.5	62.9	8.0	110.5
Tajikistan					4.4	4.1	0.8	9.3	−4.4	−4.1	−0.8	−9.3
Tanzania	90.9	96.0	21.0	207.9	3.9	3.6	0.7	8.1	87.0	92.4	20.4	199.8
Thailand	0.8	1.1	0.2	2.1	5608.3	3327.6	691.2	9627.1	−5607.5	−3326.5	−691.0	−9625.0
Togo	38.7	39.1	7.0	84.8	3.3	3.0	0.6	6.9	35.5	36.0	6.4	77.9
Tokelau					0.7	0.6	0.1	1.4	−0.7	−0.6	−0.1	−1.4
Tonga					0.1	0.1	0.0	0.2	−0.1	−0.1	0.0	−0.2
Trinidad Tbg	17.2	20.1	3.2	40.4	1.7	1.6	0.3	3.6	15.5	18.5	2.9	36.9
Tunisia	14.9	9.2	1.9	25.9	0.0	0.0	0.0	0.0	14.9	9.1	1.9	25.9
Turkey	172.4	263.5	41.6	477.5	0.8	0.8	0.1	1.7	171.6	262.8	41.4	475.8
Turkmenistan	3.4	3.2	0.6	7.2	0.1	0.0	0.0	0.1	3.3	3.2	0.6	7.1
Turks Ca. Islands	1.8	6.7	0.8	9.3	0.5	0.5	0.1	1.0	1.3	6.2	0.7	8.3
Uganda	24.3	52.8	6.7	83.8	0.5	0.4	0.1	1.0	23.8	52.3	6.6	82.7
Ukraine	23.6	19.0	4.0	46.6	0.4	0.4	0.1	0.9	23.2	18.6	3.9	45.7
UAE					139.2	128.6	24.1	291.9	−139.2	−128.6	−24.1	−291.9
UK	392.0	479.6	65.3	936.8	61.3	56.6	10.6	128.5	330.7	423.0	54.7	808.4
Uruguay	0.7	0.6	0.1	1.4	428.6	396.1	74.1	898.8	−428.0	−395.5	−74.0	−897.4
USA	440.7	321.9	57.6	820.2	677.7	2493.8	302.4	3473.9	−237.0	−2171.8	−244.8	−2653.6
Uzbekistan					0.3	0.3	0.0	0.6	−0.3	−0.3	0.0	−0.6
Venezuela	4.3	15.9	1.9	22.1	19.7	18.2	3.4	41.2	−15.3	−2.3	−1.5	−19.1
Viet Nam					595.2	392.1	245.9	1233.2	−595.2	−392.1	−245.9	−1233.2
Yemen	70.6	61.7	9.2	141.6					70.6	61.7	9.2	141.6
Zambia	6.9	6.1	1.1	14.1					6.9	6.1	1.1	14.1
Zimbabwe	7.3	5.6	1.1	14.1	0.1	0.1	0.0	0.2	7.2	5.5	1.1	13.9
Others	0.0	0.0	0.0	0.0	12.2	11.2	2.1	25.5	−12.1	−11.2	−2.1	−25.5
Total	14081.2	14591.7	2379.0	31051.8	14069.0	14580.5	2376.9	31026.4				